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TEXTILE RESEARCH JOURNAL

VOL. XXVI, NO. 6 JUNE 1956

The Study of the Phenomena of Diffusion and Adsorption of Direct Dyes in Viscose Fibers by the Method of Differential Dyeing (Part I)[1]

N. Iwanow and R. Schneider

Centre de Recherches Textiles de Mulhouse, France

Introduction

In industrial dyeing of textile fibers the dye penetrates radially from the surface toward the center of the fibers. It is extremely difficult to observe this process under the microscope owing to the lack of homogeneity of the fiber in the radial direction (layers of frequently different structure), and also owing to the fact that the thickness of a fiber is too small (10 to 30μ) for precise measurement of penetration to be possible.

However, there is another method of observing these phenomena of dyeing on fibers. Thus, in certain cases the penetration of the dye can be followed from the ends of the fiber along the line of its axis. Obviously, this process is very different from industrial dyeing, but it can be said to be a good means of laboratory study of the mechanism of the diffusion of dyes and their fixation in the fibrous material, for the longitudinal structure of the internal layers of the fiber can be considered regular over a length greatly exceeding the diameter, so that precise measurement of penetration becomes feasible.

Viscose fibers are particularly suitable for the application of this technique by reason of their very structure, the "skin" being much less permeable than the "core" to aqueous solutions of dyes. This property is the basis of the "differential dyeing" described by numerous research workers, and it has enabled us to perfect an original method [3, 4, 5], which is normally adopted in our laboratories (*a*) for determining the cause of streaks or stripes which occur in dyeing when viscose fibers of different qualities are used, or (*b*) again, for studying certain phenomena such as the diffusion of dyes within the "core" of viscose fibers.

Since our first publication, some years ago [3], further knowledge has been gained concerning the secondary phenomena which may occur when our method is applied: deformation of the fiber by cutting, instability of the fiber, migration of the dye. These results have led us to revise and improve very substantially the technique originally followed, so as to be able to undertake a more accurate study of the diffusion, adsorption, or migration of dyes within cellulosic material.

We will limit this paper to the description of the new techniques adopted in the laboratory, merely giving a few examples of their possible applications; to some, however, we will revert later in more detail.

The first part will be devoted to the kinetic study of penetration in *individual* viscose fibers, in a special microcell and characterized by the use of one and the same piece of fiber for a large number of dyeings,

[1] This paper also appears in French in the current (June) issue of the Bulletin of the Institut Textile de France.

repeated under systematically different conditions.

In a *second part* we shall make a statistical study of populations of fibers (manufactures, batches, rayon staple and filament yarns and fabrics), characterized by simultaneous dyeing of thousands of pieces of cut fibers.

PART I.

Kinetic Study of Penetration in Individual Fibers

A. History and Principle of Method

Differential dyeing of viscose fibers has been studied by numerous authors, and fairly complete information on the subject is to be found, for example, in the article "Staining of Viscose Rayon Cross Sections" by P. H. Hermans [2]. Side by side with other tests, the author made the first attempt to measure the phenomenon quantitatively, as described in this article. Unfortunately, he does not give any details of the technique used for these measurements, simply stating that the fibers, after having been cut (preferably with a razor blade), are immersed in a dye solution and examined under the microscope. In this way, Hermans measured the axial penetration as a function of the dyeing time on a series of rayons of different manufacture. For three sorts of rayon he gives the results of measurements, for the others he only states a calculated coefficient K. All the measurements were made using only one dye, Solophenyl Fast Blue-Green B.L., at ordinary temperature.

From the measurements thus made he deduces that axial penetration of the dye in the case of differential dyeing follows the diffusion law $P = K \cdot \sqrt{t}$, derived from Fick's law (wherein P = penetration, t = dyeing time, and K = proportionality factor), and defines it as "anisotropic diffusion."

Measurements of this type carried out in our laboratory occasionally enabled us to achieve highly accurate results, so that we were led to use this technique both with a view to ascertaining the characteristics of different sorts of viscose and to making a thorough study of the dyeing phenomena themselves. However, we very quickly found that the penetration of a dyeing solution varied to such an extent with all sorts of outside factors that the studies we contemplated could be undertaken only by a new method and an improved technique.

The simplest process for a quantitative study of differential dyeing can be carried out as follows: an individual viscose fiber about 10 to 15 mm. long is carefully cut at one end by a new razor blade in order to obtain as perfect a cut, as perpendicular to the axis as possible. It is then fixed by its other end on a slide by means of a drop of melted paraffin wax. The slide with the prepared fiber is plunged into an adequate dyeing solution (we used a 2% aqueous solution of Chlorazol Sky Blue FF at ordinary temperature). After predetermined dyeing times, the slide is removed from the dyeing solution, the fiber is covered with a cover glass and then examined under the microscope.

It will be observed (Figure 1) that the dye has penetrated into the core of the fiber, while the outside layer of the latter is not appreciably stained. With a micrometrical eyepiece, the depth to which the dye has penetrated in a given dyeing time is measured. The depth of penetration as a function of the dyeing time can then be shown in a graph on the basis of the values found.

The most apparent defects of this technique are, on the one hand, the pressure of the cover glass on the fiber, which immediately slows down the speed of penetration of the dye, and on the other hand, the evaporation of the water under the cover glass, which causes a variation in the concentration of the dye solution.

The results we have obtained by using this simple process have been disappointing in general. The accuracy achieved has been no greater than that reached by P. H. Hermans. To show how imprecise such measurements are, we have plotted in Figure 2,

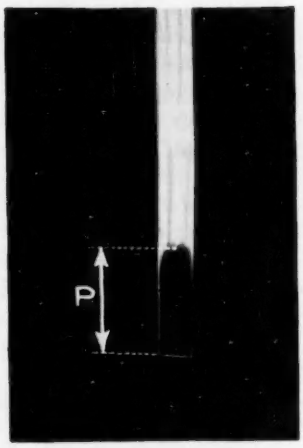


Fig. 1. Axial penetration by one end of a viscose fiber (polarized light).

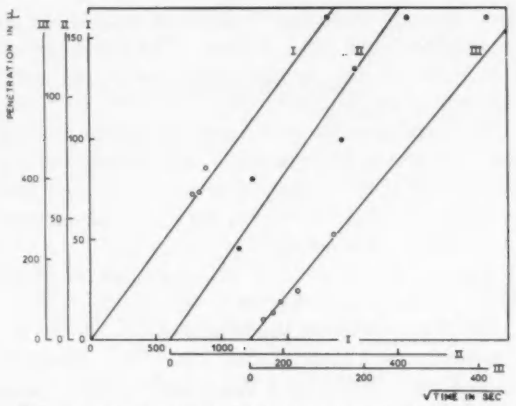


Fig. 2. "Penetration straight lines" of Solophenyl Fast Blue Green BL for three viscose rayons (after P. H. Hermans).

from the values taken from a table in P. H. Hermans' article, the "penetration straight lines" of Solophenyl Fast Blue Green B.L. for three viscose rayons (the only ones for which the experimental results are given).

Moreover, we have found that the elementary filaments of one and the same rayon yarn showed very different penetrations under identical dyeing conditions. For instance, in an ordinary French rayon dyed for 2 hr. and 20 min. at 24° C. with a 2% solution of commercial Chlorazol Sky Blue FF, the penetrations vary from 16 to 39μ. The variations in staple fibers are even more enormous.

It is thus seen that in a series of comparative tests relating, for instance, to the influence on penetration of the variation in concentration of the dye or of the electrolyte, one can never be sure of having an identical support if a new fiber of the same sort of viscose is used for each dyeing.

This very serious drawback has led us to develop a new method of permitting precise measurement on a support with constant properties.

The principle of this method consists in

a. Using a special microcell meeting all the conditions necessary for microscopic examination and ensuring integrity of the fiber, that is to say, protecting it from all mechanical actions.

b. Carrying out repeated dyeings on one and the same piece of fiber (a few millimeters long), which is made possible by extracting the dye with pyridine after each dyeing, thus ensuring identity of the support.

c. Making sure that the properties of the support have not varied by reverting from time to time to the conditions under which the first dyeing was carried out and finding the same results.

The Microcell

First we experimented with a series of simple apparatus:

a. A slide with a central channel a few hundredths of a millimeter deep, sufficient to take the fiber freely and protect it from the pressure of the cover glass,

b. Special cells made of pieces of glass cemented together, with devices for the inlet and outlet of the dye solution, which enabled the concentration of the dye to be kept constant.

We also tested various methods of fixing the fibers in the cells. In this way we determined the body of conditions which must be met by a microcell if it is to furnish sufficiently precise and reproducible experimental results.

1. The depth of the channel in which the fiber is fixed and observed must be about 20 to 30μ. (With a very deep channel the absorption of light by the dye solution in which the fiber is immersed becomes so great that observation of the penetration front and the measurement of its advance are very difficult.)

2. The thickness of the upper wall of the cell, through which examination is made under the microscope, must be equal to that of a cover glass and permit of using objectives with short working distance.

3. The total thickness of the piece placed in the luminous path for examination under the microscope must not be excessive. The possible reduction of the numerical aperture of illumination with a microscope of ordinary construction must not make observation difficult.

4. The cell must have means of inlet and outlet for the dye solutions or other reagents ensuring continuous circulation, so that the concentration is kept constant during a test.

5. The arrangement of the cell must be such that all its parts can be thoroughly cleaned.

6. The cell must protect the fiber from all pressure, even transient, throughout all manipulations.

7. No adhesives likely to influence the dyeing phenomenon may be used for assembling the different parts of the apparatus. If possible, the cell should not comprise any material other than glass.

8. The fiber must be fixed without the use of adhesives and sufficiently firmly to permit its being handled permanently and uninterruptedly (for a period of one month and more).

Some difficulties were encountered in making a cell meeting all these conditions, for the technology of glass-working does not permit making any desired type which does so, whatever it may be.[2] The solution we adopted for this problem led us to make the cell described later (Chapter C, "Technique of the Method"), which has only two pieces of glass not cemented together.

Execution of Repeated Dyeings on the Same Piece of Fiber

Repeated dyeings on one and the same piece of fiber can be carried out only if it is possible to extract the dye from the fiber after staining. Moreover, it is essential that the properties of the fiber shall not be changed by this extraction.

Preliminary tests showed that the dye introduced into the fiber by differential dyeing could be completely eliminated in a large volume (50 cm.^{3}) of cold 20% aqueous solution of pyridine. This extraction does not change the properties of the fiber, because after the latter had been washed in water a new dyeing, carried out in the same way, once again gave exactly the same penetration values as those originally observed.

Thanks to this technique it was therefore possible to ensure identity of cellulosic support for the series of comparative tests which we wished to undertake.

B. Potential Applications of the New Method and Experimental Results

All the tests which will be described, except those in the section on the "influence of the nature of the dye," namely, 47 dyeings in all, were carried out on one and the same piece of fiber. The figures which are circled on the various graphs show the serial numbers of the dyeings.

The tests described in the section "influence of the nature of the dye" were made subsequently, on another piece of fiber which was dyed 61 times. The results of 33 of these dyeings were used for plotting the graph of Figure 6.

All dyeing was done at a temperature of 20 to 22° C. (temperature of the laboratory).

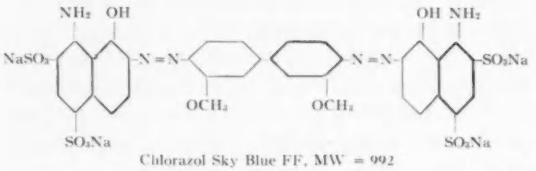
The dyes used were the following:

Commercial Chlorazol Sky Blue FF, (analysis: 45.60% dye, 29.65% Na_2SO_4, 17.65% NaCl, moisture 5.60%)

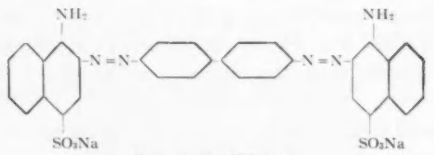
Pure Chlorazol Sky Blue FF (Color Index 518), free from electrolyte, obtained by purification of the commercial dye by the sodium acetate process [8, 9, 1].

Commercial Congo Red (not analyzed)

Pure Congo Red (Color Index 370), free from electrolyte, obtained by purification of the commercial dye by the sodium acetate process.



Chlorazol Sky Blue FF, MW = 992



Congo Red, MW = 696

1. *Reproducibility and Precision of Measurements—The Function Penetration—Dyeing Time*

We carried out a dyeing and measured the depths of penetration between 0 and 100μ at different intervals of time. Dyeing was then stopped and the dye was eliminated from the fiber. After the latter had been washed, dyeing was recommenced with the same dye solution as previously used. This was repeated a certain number of times, always with the same dye solution. The results obtained are shown in the graph of Figure 3. Dyeings 6 through 14, 17, 20, and 28 were done with a solution containing, per liter:

[2] Owing to these various imperative requirements it was not possible to contemplate using Millson and Turl's Microdyeoscope [6, 7], for the microdyeoscope cell, made of two glass plates separated by a metal mount and two rubber rings (to ensure tightness and to protect the glass), is 3 to 4 mm. deep. Now, this depth is much too great to permit of measuring penetration: the layer of the dye solution becomes too dark and the "penetration front" in the fiber can no longer be seen.

On the other hand, the method of fixing the fiber in the microdyeoscope by winding it round a small metal wire frame does not meet our requirements, furthermore, it is impossible to attempt to reduce the size of this frame to that of the cell we need. Moreover, with this method of fixing the fiber it is not possible to observe the ends of the fiber with accuracy.

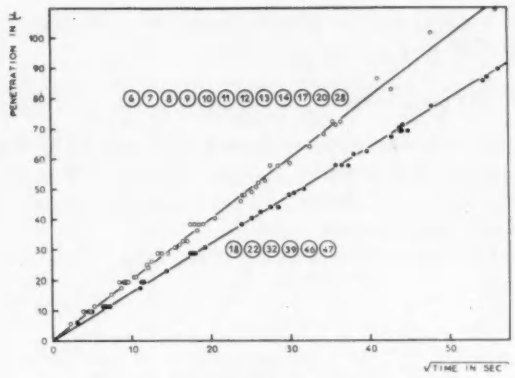


Fig. 3. Reproducibility of measurements.

9.12 g. Chlorazol Sky Blue FF
5.93 g. Na_2SO_4
3.53 g. NaCl
(20 g./liter commercial dye solution).

Dyeings 18, 22, 32, 39, 46, and 47 were done with a solution containing, per liter:

10 g. purified Chlorazol Sky Blue and
10 g. NaCl.

The scale of the graph is too small to enable us to show each dyeing by its straight line or even to use different signs for the figurative points corresponding to the various serial numbers of the dyeings. (The mean straight line of the series 6 to 28 corresponds to *12 straight lines*, and the mean straight line of the series 18 to 47 corresponds to *6 straight lines*).

An additional analysis of the accuracy and reproducibility of the measurements has been summarized in Table I, with respect to a certain number of repeated dyeings. Opposite the measured penetrations P we have shown the penetrations P' (calculated from a mean straight line for the experimental values $\sqrt{t}$), as well as their difference ΔP.

It will be noted that out of 44 dyeings, the deviation ΔP exceeds 1μ in only 7 cases. In all 44 cases this deviation is smaller than 2μ, which, for our experimental conditions, corresponds to 1 division of the eyepiece micrometer.

The average deviation $(\Delta P)_M$ is equal to $\Sigma|\Delta P|/44 = 0.52\mu$.

When some of the dyeings of this series are studied individually, the concordance of the measured points with a straight line is still greater: the average deviation $(\Delta P)_m$ between the measured penetrations and a calculated straight line meeting the condition $\Sigma\ \Delta P = 0$ is substantially equal to $\pm 0.25\mu$.

On the basis of these results it can therefore be concluded that

1. The measurements relating to an individual dyeing are well aligned on a straight line and there-

TABLE I. Reproducibility of Measurements: Differential dyeing of a viscose fiber with pure Chlorazol Sky Blue FF 1% and NaCl 1% (room temperature) measured penetrations and calculated penetrations

Dyeing No.	Dyeing time (sec.)	Penetration in μ: Measured P	Penetration in μ: Calculated P'	$\Delta P = P - P'$
18	45	11.5	11.77	−0.27
	120	17.3	18.34	−1.04
	370	30.7	31.21	−0.51
	810	44.1	45.46	−1.36
	1390	57.6	59.12	−1.52
	2000	69.1	70.65	−1.55
32	25	9.6	9.12	+0.48
	125	19.2	18.7	+0.50
	303	28.8	28.35	+0.45
	760	44.1	44.08	+0.02
	1420	61.4	59.74	+1.66
	1910	70.0	69.07	+0.93
	2280	76.8	75.34	+1.46
46	40	11.5	11.17	+0.33
	133	19.2	19.24	−0.04
	325	28.8	29.31	−0.51
	690	42.2	42.07	+0.13
	1010	49.9	50.60	−0.70
	1330	57.6	57.87	−0.27
	1920	69.1	69.25	−0.15
	2950	85.4	85.50	−0.10
22	45	11.5	11.77	−0.27
	132	19.2	19.18	+0.02
	310	28.8	28.66	+0.14
	570	38.4	38.37	+0.03
	930	48.5	48.62	−0.12
	1330	57.6	58.87	−0.27
	1820	67.1	67.46	−0.36
	1940	69.1	69.61	−0.51
39	10	5.8	6.27	−0.47
	45	11.8	11.77	+0.03
	205	23.0	23.56	−0.56
	310	28.8	28.66	+0.14
	630	40.3	40.26	+0.04
	1280	57.6	56.8	+0.80
	1950	71.0	69.78	+1.22
	3150	89.2	88.32	+0.88
47	25	9.6	9.12	+0.48
	125	19.2	18.70	+0.50
	305	28.8	28.42	+0.38
	890	48.0	47.58	+0.42
	1570	62.4	62.75	−0.35
	3000	86.4	86.21	+0.19
	3830	97.8	97.24	+0.56

fore the depth of penetration of the dye varies in proportion to $\sqrt{t}$.

2. Thanks to this method it is possible to carry out with a great degree of reproducibility numerous successive dyeings followed by subsequent extraction of the dye by pyridine.

2. *Influence of the Electrolyte Concentration on Penetration*

To study the influence of the concentration of NaCl in the dyebath on the kinetic of penetration of Chlorazol Sky Blue FF, the dyeings shown in Table II were carried out.

TABLE II

Dyeing No.	Concentration of dyestuff in bath (g./liter)	Concentration of NaCl in dyeing bath (g./liter)
33, 34, 35	10	0
41	10	0.1
42	10	0.5
43	10	1
36, 37	10	5
32, 39, 46	10	10
21, 45	10	20
44	10	50

The results obtained are shown in Figure 4. It will be seen that with a constant dye concentration the slope of the "penetration straight lines" becomes steeper as the concentration in electrolyte becomes weaker. In other words, *the speed of penetration of the dye into the fiber increases when the concentration in electrolyte decreases.*

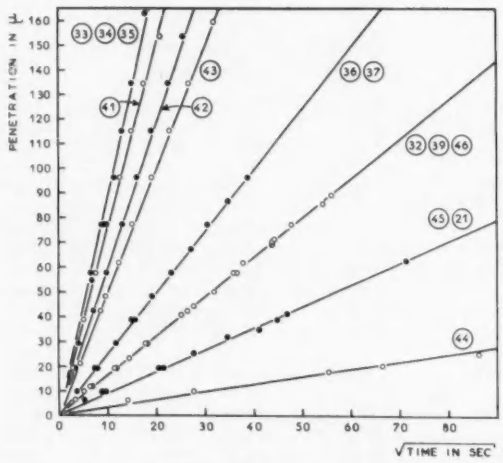


Fig. 4. Influence of electrolyte concentration on penetration.

3. *Influence of the Dye Concentration on Penetration*

In a similar way we studied the influence of the concentration in pure Chlorazol Sky Blue FF in the dye bath on its kinetic of penetration, the content of NaCl being constant.

The dyeings shown in Table III were carried out.

TABLE III

Dyeing No.	Concentration of dyestuff in bath (g./liter)	Concentration of NaCl in dyeing bath (g./liter)
29	0.01	5
27	0.1	5
26	0.5	5
25	2	5
24	5	5
23	10	5
31	20	5

The results obtained are shown in Figure 5. In this case the inverse relation from the preceding one will be noted: with a constant concentration of electrolyte the slopes of the "penetration straight lines" become less steep with the reduction of the concentration of dyestuff. This means that *the speed of penetration of the dye into the fiber becomes slower when its concentration in the dyeing bath becomes weaker.*

4. *Influence of the Nature of the Dye on Penetration*

We have compared the kinetic of penetration of Chlorazol Sky Blue FF with that of Congo Red.

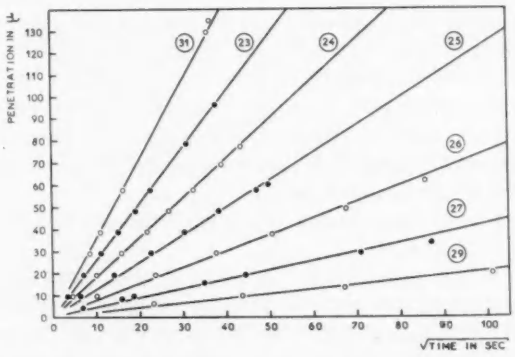


Fig. 5. Influence of dye concentration on penetration.

As we have already stated in the introduction to this chapter, this series of measurements was made separately, on another fiber. This study necessitated a minimum of 33 dyeings.

For convenience of comparison of the two dyes, we have plotted in the graph of Figure 6 the slopes of the "penetration straight lines" $dP/d\sqrt{t}$, as a function of the decimal logarithm of the molar concentration of dye in the bath, for different concentrations of NaCl in the dyeing bath and for both dyes (see Table IV).

TABLE IV

Curve	Concentration of dyeing bath in NaCl (g./liter)
Dye: Chlorazol Sky Blue FF	
A	0.1
B	1
C	5
D	20
E	50
Dye: Congo Red	
a	0.1
b	1
c	5
d	20
e	50

As can be seen, the two dyes lead to similar but not identical families of curves.

We shall revert in a later article to the interpretation of these experimental results.

5. *Migration of Dyes*

The tests which will be described in this section are highly important for correct application of the techniques of the statistical method which will be explained in the second part of this paper.

On the other hand, it is a well-known fact that certain industrial dyeings are carried out by adding electrolytes to the bath during dyeing itself. It has occurred to us that our method may be useful in attempting to explain the mechanism of the phenomena which may then take place. For this reason we made a series of tests which we shall describe by way of examples and which can be looked upon as the starting point of further and more thorough studies.

When, during differential dyeing, the dye solution is instantaneously removed by some other solution

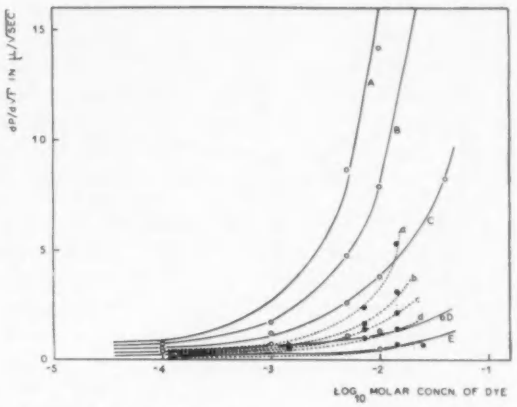


Fig. 6. Influence of the nature of the dye on penetration.

(for instance, a solution of pure electrolyte), *the initial penetration process is interrupted.*

This does not mean, however, that the dye no longer progresses within the fiber, for another process, that of *migration of the dye,* may then commence.

In the same way as we had previously measured the movement of the "penetration front" of a dye in the fiber, we can also measure the movement of the *"migration front"* of the same dye.

That is what we did in the following series of tests, in which the composition of the solution intended to wash the fiber after a certain dyeing time was varied. We have selected three examples, the first corresponding to an electrolyte concentration weaker than that of the initial dyeing bath, the second to an identical concentration, and the third to a stronger concentration.

Example No. 1

The fiber was dyed with a solution containing per liter:

9.12 g. Chlorazol Sky Blue FF
3.53 g. NaCl
5.93 g. Na_2SO_4 (20 g./liter solution of commercial dye).

The straight line in Figure 7 (white circles) corresponds to this dyeing.

When the penetration of the dye had reached a certain value, the dye solution was replaced instantaneously (see section "Technique," paragraph "Change of Reagent") by a solution of pure elec-

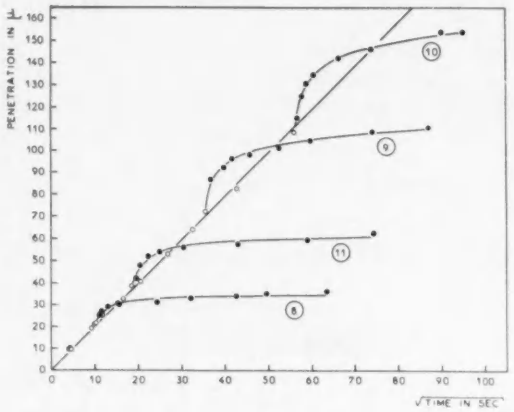


Fig. 7. Influence of the depth of penetration on migration.

trolyte of 5 g. Na_2SO_4/liter, and we continued to measure the progression of the dye. It will be seen that in each test the "migration front" suddenly accelerated its progression in the fiber and then slowed down again gradually (curves 8, 11, 9, 10, black circles).

In test 8 the solution was changed when penetration had reached 21μ; in test 11, 38.4μ; in test 9, 72μ; and in test 10, 108.5μ.

It is quite clear that the size of this "migration jump" is a function of the depth of penetration of the prior differential dyeing.

At the very moment when the dye solution is eliminated by a solution of pure electrolyte, a very short and transient action of a mixture of these two solutions on the dyed fibers is possible. It is therefore of interest to ascertain the effect of such a mixture on migration.

For this purpose we made parallel tests with solutions of pure electrolyte and with solutions of electrolyte (of the same concentration) containing small quantities of dye.

The results obtained in these parallel tests are shown in Figure 8 by curves 9 and 14 (black circles).

The prior differential dyeing was carried out with a 20 g./liter solution of commercial Chlorazol Sky Blue FF. The straight part of the curve (white circles) corresponds to this dyeing. At the instant when penetration had reached 72μ (end of the straight part), we instantaneously replaced the dye solution:

a. By a solution containing pure electrolyte, *i.e.*, 5 g. Na_2SO_4/liter (curve 9).

b. By a solution containing 5 g. Na_2SO_4 and 0.12 g. Chlorazol Sky Blue FF/liter (curve 14).

As can be seen, no substantial difference is to be observed between the migration curve corresponding to the electrolyte alone and that corresponding to the electrolyte with dye added. In particular, at the beginning of migration the curves are merged. Now, in practice a mixture of the dye solution and the washing electrolyte solution can subsist only for a few seconds at the most. This factor can therefore be neglected when studying migration.

Example No. 2

The migration tests described so far were made with weaker electrolyte solutions than the concentration of electrolyte in the dyeing bath.

A variation which is of very special interest is the case where the concentration in electrolyte is selected identical in the dye solution serving for the differential dyeing and in the washing solution.

This case is shown in Figure 8 by curves 12 and 13 (black circles). For these two tests, differential dyeing was leaded to a penetration of 50μ (straight part, white circles) with a solution containing per liter:

9.12 g. Chlorazol Sky Blue FF
3.53 g. NaCl
5.93 g. Na_2SO_4

(20 g./liter commercial dye solution).

Then this solution was replaced instantaneously:

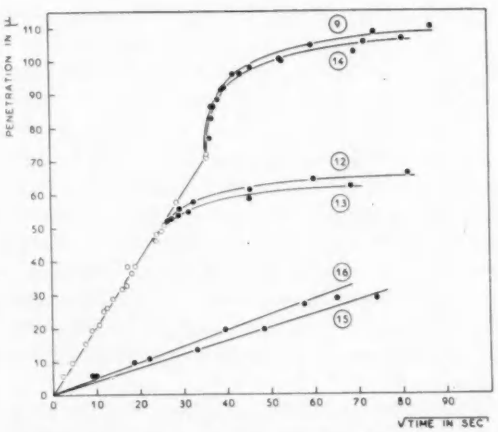


Fig. 8. Effects of migration when the fiber is washed after dyeing.

a. In test 13, by a solution containing
   3.53 g. NaCl
   5.93 g. Na_2SO_4 per liter;
b. In test 12, by a solution containing
   3.53 g. NaCl
   5.93 g. Na_2SO_4
   0.12 g. Chlorazol Sky Blue FF per liter.

It will be noted that in these cases also migration of the dye takes place. However, it is not so extensive as with diluted solutions of electrolyte (see tests 9 and 14). On the other hand, with regard to the effect of the presence of a small quantity of dye in the washing electrolyte, the same conclusions apply as in the case of the preceding tests (tests 9 and 14).

However, although this effect is not appreciable in itself, these very diluted solutions of dye are per se perfectly capable of causing normal penetration on virgin fiber.

This can be seen in the same graph, Figure 8, from tests 16 and 15. In test 16, differential dyeing was carried out with the solution which had been used for washing in test 14, and in test 15, a differential dyeing was effected with the solution which had been used for washing in test 12.

Example No. 3

When washing solutions with very high electrolyte concentration are used, the migration effect becomes practically nil. A differential dyeing was done with a 20 g./liter solution of commercial Chlorazol Sky Blue FF (penetration straight line 6 in Figure 9, while circles) until a penetration of 58.5μ was reached. The dye solution was then eliminated by a 100 g./liter solution of NaCl.

From that moment the progression of the dye was practically nil (horizontal straight line 6', black circles).

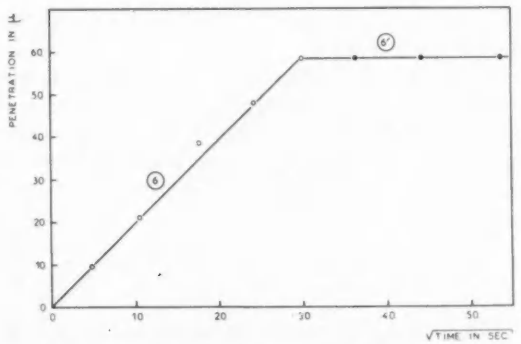


Fig. 9. "Arresting" of penetration.

From all these tests it can be concluded that the extent of the migration of the dye depends on the concentration in electrolyte of the washing solution and on the depth of penetration reached by the prior dyeing.

6. *Differential Dyeing on Pre-Dyed Fiber*

So far we have been studying the behavior of virgin fiber. But it is just as interesting to study differential dyeing on pre-dyed fiber, that is to say, the influence of the presence of dye previously introduced in the fiber on the speed of penetration. For this purpose we made the following tests:

(i) The fiber already used for the preceding tests was pre-dyed *throughout its mass* by immersion at ordinary temperature in a dye solution containing per liter:

10 g. commercial Congo Red
25 g. anhydrous pyridine.

The pyridine was added to accelerate dyeing at ordinary temperature. In this way, after a long time (64 hr.), we obtained uniform coloration throughout the length of the fiber.

After washing for 90 min. in running water to eliminate the pyridine, the fiber pre-dyed with Congo Red was subjected to ordinary differential dyeing (dyeing 47) with a solution containing per liter:

10 g. pure Chlorazol Sky Blue FF
10 g. NaCl.

The results of this penetration test are shown in Figure 10. In addition to the straight line 47 (black circles) corresponding to the penetration in the pre-

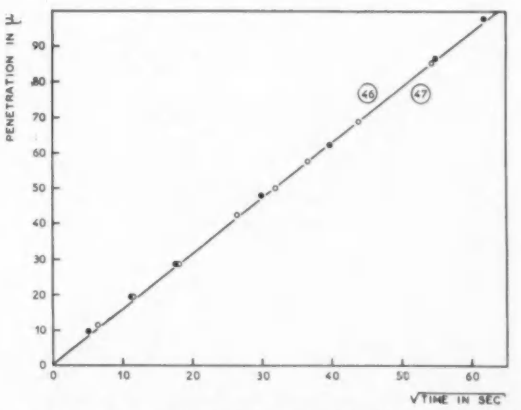


Fig. 10. Penetration on fiber pre-dyed with Congo Red.

dyed fiber, we have plotted the straight line 46 (white circles) corresponding to the differential dyeing of virgin fiber with the same solution of Chlorazol Sky Blue, that is to say, of fiber which had not been previously dyed with Congo Red. The two straight lines are exactly superimposed on each other.

The absence of any variation in the speed of penetration in the pre-dyed fiber led us to check whether the core of the latter had actually been dyed by the Congo Red. For this purpose a bundle of fibers of the same batch of viscose was dyed under the same conditions in the pyridinic solution of Congo Red and also washed for 90 min. in running water. The fibers were then cut with a microtome. An examination of the sections showed that the core of the fibers was even more deeply dyed than the skin. Even after the sections had been soaked in water for 60 hr., it was not possible to extract the dye. It was thus definitely established that in the test represented by the straight line 47 the core of the fiber was dyed and that the Congo Red could not be extracted by washing in water for 90 min.

This test therefore showed that the presence of a certain quantity of Congo Red previously introduced into the fiber by dyeing in a pyridinic solution had no influence on the speed of penetration of the Chlorazol Sky Blue FF during subsequent differential dyeing.

The fiber can also be pre-dyed Congo Red by differential dyeing with this dye. This test was carried out in the following manner:

(ii) The same fiber which had been used previously was subjected to differential dyeing with a 14 g./liter solution of commercial Congo Red. After

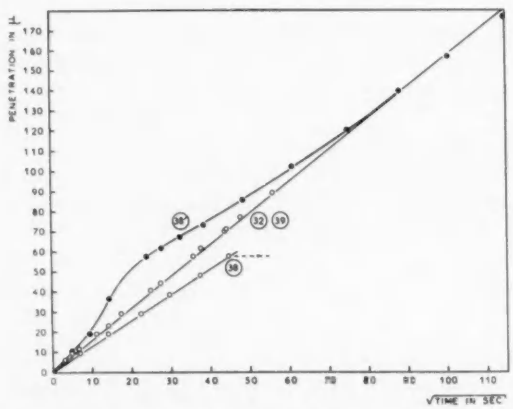


Fig. 11. "Overpenetration" in a fiber prepenetrated by Congo Red.

34-min. dyeing, when the penetration front had reached the depth of 58μ, the Congo Red solution was instantaneously replaced by a solution containing per liter:

10 g. pure Chlorazol Sky Blue FF
10 g. NaCl.

Immediately upon the solution being changed, penetration of the Chlorazol Sky Blue commenced at once by the cut end of the fiber in the part already pre-dyed, while the "penetration front" of the Congo Red remained stationary at the depth of 58μ. The straight line 38 in Figure 11 corresponds to the penetration of the Congo Red, the curve 38' to that of the Chlorazol Sky Blue in the presence of Congo Red. For this latter curve we took the instant when penetration of the Congo Red was arrested ($t = 34$ min., $P = 58\mu$) as the beginning of the test ($t = 0$).

Finally, to demonstrate the stability of the fiber during the test and for purposes of comparison, we have plotted in the same graph two straight lines 32 and 39, corresponding to the penetration of the Chlorazol Sky Blue in the fiber containing no Congo Red, before and after test 38. The curve of penetration of the Chlorazol Sky Blue in the presence of Congo Red first of all substantially deviates from the normal straight line (32, 39), then gradually swerves back and becomes superimposed on it.

It is therefore obvious that, contrary to what occurred in test 47, the presence of Congo Red introduced into the fiber by differential dyeing has a substantial influence on the speed of penetration of the Chlorazol Sky Blue FF when the fiber is subsequently subjected to differential dyeing with the latter dye.

(iii) If Chlorazol Sky Blue is substituted for Congo Red for the first differential dyeing (pre-dyeing), similar results to those of the previous test are obtained with regard to the second differential dyeing (overdyeing).

This is shown in Figure 12. This time the first differential dyeing (pre-dyeing) was done with a solution of pure Chlorazol Sky Blue FF, containing no electrolyte, at 10 g./liter. The second differential dyeing (overdyeing) was done with a solution containing per liter:

10 g. pure Chlorazol Sky Blue
10 g. NaCl.

The intensity of coloration of the second dyeing being greater than that of the first, it is possible to

observe and measure the displacement of the second "penetration front" on the pre-dyed part of the fiber. After a certain time the second "penetration front" reaches the same depth at which the first "front" had stopped, then goes beyond it and continues its progress over the nondyed part of the fiber.

This test was repeated three times, the pre-dyeing being stopped at a different depth of penetration each time:

In test 34 at 55μ
In test 33 at 96μ
In test 35 at 163μ.

These pre-dyeings are shown by the three superimposed straight lines 34, 33 and 35 in Figure 12. The gait of the overdyeing corresponding to each of these three tests is shown in the curves 34′, 33′ and 35′.

For purposes of comparison and to check the stability of the fiber during these tests, we have also plotted in the same graph the straight lines 32 and 39, corresponding to the penetration of the solution of 10 g. pure Chlorazol Sky Blue FF and 10 g. NaCl per liter in the virgin fiber.

When these various curves are compared, it is seen that

1. The fiber has remained stable during these tests (the straight lines 32 and 39 are superimposed on each other);

2. The greater the depth of penetration during pre-dyeing (34, 33, 35), the more the curve corresponding to the overdyeing (34′, 33′, 35′) deviates from the normal straight line (32, 39);

3. The overdyeing curves, which at first deviate substantially from the normal straight line, approach it again later as dyeing proceeds.

(iv) Finally, if, instead of using the pure Chlorazol Sky Blue solution for the first differential dyeing, a solution containing per liter

10 g. pure Chlorazol Sky Blue
5 g. NaCl

is used, and if the overdyeing is always done with the solution containing

10 g. pure Chlorazol Sky Blue
10 g. NaCl per liter,

results similar to those of the preceding test are obtained, and the same conclusions can be drawn.

This last series of tests is illustrated by Figure 13. The depth of penetration at which the pre-dyeing was stopped was 38μ in test 37 and 96μ in test 36.

The corresponding overdyeing curves are curves 37′ and 36′ (black circles).

These few tests show that the field of differential dyeing on pre-dyed fiber, which we have begun to explore, is very vast and extremely interesting. It is remarkable to find that the presence of a certain quantity of dye fixed in the core of the fiber has, or has not, an influence on the evolution of subsequent differential coloration according to the manner in which such dye has previously been fixed on the cellulosic material.

Other tests along these lines, made by the statistical method, will be described in the second part of this publication. We hope to be able, later on, to

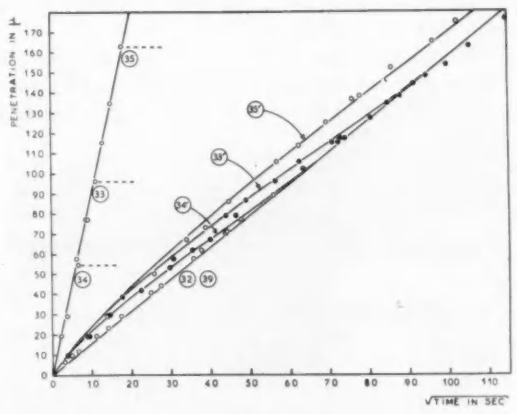


Fig. 12. "Overpenetration" in fiber prepenetrated by pure Chlorazol Sky Blue.

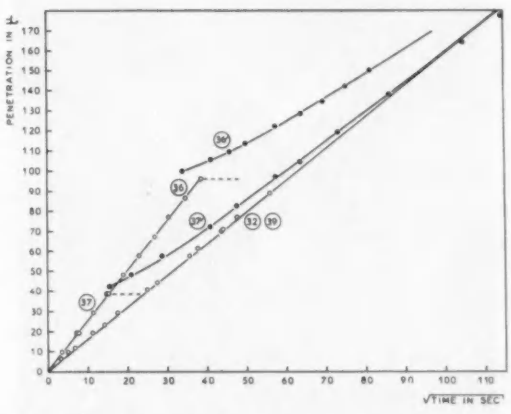


Fig. 13. "Overpenetration" in fiber prepenetrated by Chlorazol Sky Blue with the addition of NaCl.

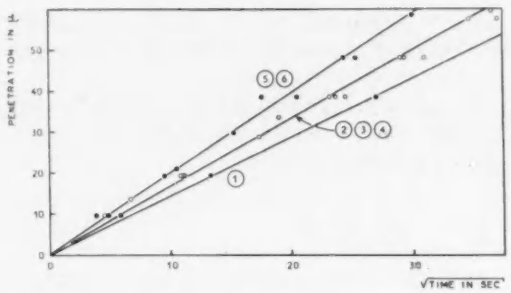


Fig. 14. Stabilization of the penetration straight line.

derive new data from them concerning the mechanisms by which direct dyes become fixed in viscose fibers.

7. *Stability of Fiber—Deformations Caused by Cutting*

In Figure 14 we have represented the measurements relating to the very first dyeings of the fiber used for the tests already described.

All these dyeings were done under the same conditions with a 20 g./liter solution of commercial Chlorazol Sky Blue.

It will be observed that the slope of the "penetration straight lines" varied in the course of these first dyeings and did not become stabilized until after the fifth.

Checks were made by means of tests inserted subsequently between the various series (see in paragraph "Reproducibility of Measurements" the dyeings 6 through 14, 17, 20, 28 and 18, 22, 32, 39, 46, 47 done with the same dye solution), and we found that the fiber remained in a stable state from the sixth to the forty-seventh dyeing. This shows great stability of the fiber under the numerous physicochemical treatments to which it was subjected during these dyeing operations which were spread over a period of 37 days.

But on the other hand, from our experience in this field we noted that the fibers are very sensitive to mechanical actions. Owing to this fact, great care must be taken in handling the fibers.

In particular, there is no doubt whatever that the inevitable cutting process greatly influences the speed of penetration. If this operation is carried out with inadequate means, the speeds of penetration are excessively slow during subsequent differential dyeing.

The particularly thorough and far-reaching study we have made by the statistical method, to which we shall revert in detail in the second part of our publication, has led us to the following supposition: when a fiber is cut, structural elements are displaced on the cut surface, giving rise locally to denser zones in the substratum, which involves a reduction in the speed of penetration of the dye (as compared with an "ideal" cut).

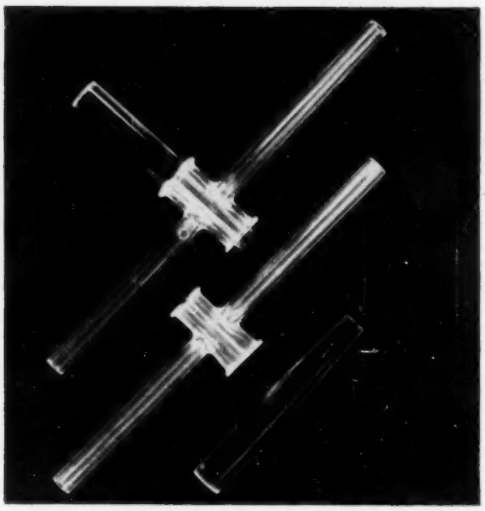


Fig. 15. Microcell, scale: 1 cm. for 1, 8 cm.

C. Technique of Method

1. *Description of the Microcell*

The microcell can be compared with a glass stopcock, such as is used in laboratories (Figure 15), comprising a female part or "barrel" (Figure 16, *a*) and a "key" (*c* in Figures 16 and 17).

The inside surface of the barrel is finished with greater precision than is an ordinary stopcock, in the geometric form of a cone, by optical grinding and

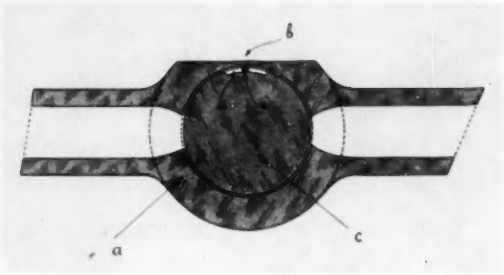


Fig. 16. Microcell, cross section.

polishing. A part of the outside surface of the barrel is cut *optically flat* and polished. In this way the cell is given an upper wall about 0.1 mm. thick, which acts as a cover glass (Figure 16, *b*). The inlet and outlet tubes for the liquids are welded laterally to the tubular body.

The second part of the cell, the male piece or "key" (*c* in Figures 17 and 16) is also made of glass, but unlike the same part of an ordinary stopcock it is not pierced. An observation channel, properly so-called, has been hollowed in its surface (Figure 16, *d* and 17, *d*), 30 to 40μ deep. This channel is prolonged to the inlet and outlet tubes (Figure 17, *f*).

The liquid flows along the channel between the barrel and the key of the cell. The observation channel is oriented in the direction of the axis of the male part and at one end it has a groove in which the fiber is fixed (Figure 19).

2. Fixing the Fiber in the Cell

The best method of fixing a fiber in the cell appears to us to be as follows.

At one end of a small length (1 to 1.5 mm.) of nylon bristle 0.3 mm. in diameter, a hole is pierced with a needle and the fiber is threaded through this hole (Figure 18).

The two ends of the fiber are cut, as required by the method, with a new and intact razor blade.

The piece of nylon-bristle with the fiber threaded through is then transferred on to the male part of the cell and is wedged in the groove in the observation channel (Figure 19). Thanks to the rim which has formed on the bristle on piercing it, it fits frictionally in the groove and fixes the fiber by pressing it against the groove wall. It is pointed out that

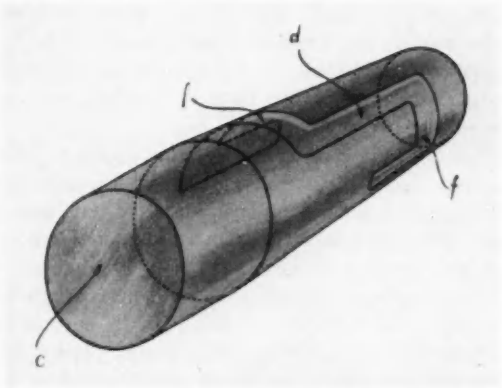


Fig. 17. Microcell, male part or "key" with channels.

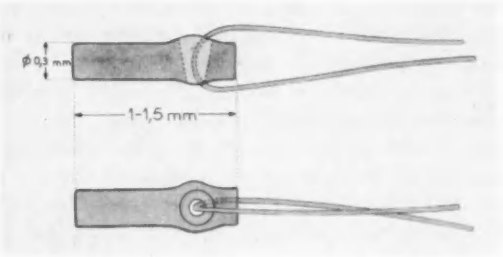


Fig. 18. Fixing of fiber on nylon bristle.

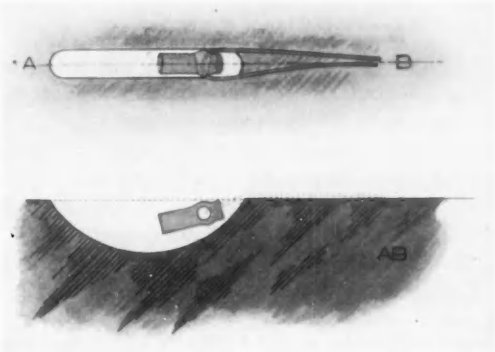


Fig. 19. Fixing of nylon bristle with fiber in the groove on the male part of the cell.

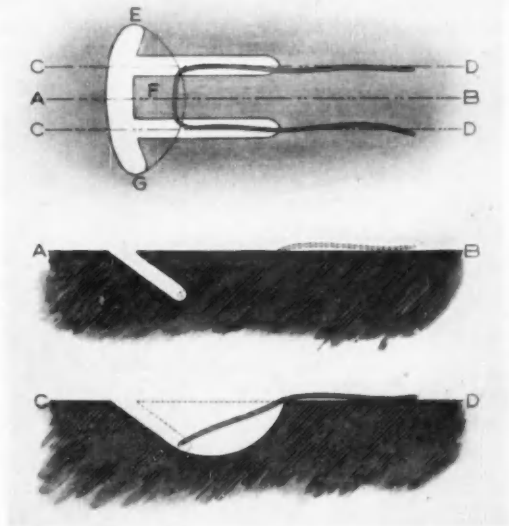


Fig. 20. Another method of fixing fiber, on a spur cut in the male part of another cell.

this pressure is exerted at a considerable distance from the ends of the fiber and cannot therefore influence penetration of the dye.

In another microcell we have also used a different, more complicated device to fix the fiber. This is a sort of spur cut in the bottom of the observation channel, to which the fiber is hooked. Details of this construction and the method of attaching the fiber can be seen in Figure 20. The spur is formed by two parallel, longitudinal slits, *cd* and *c'd'*, and a smaller, transversal slit *efg*, which cuts slantwise into the glass.

3. *Liquid Inlet and Outlet of the Cell*

In Figure 21 we have shown the cell *a* diagrammatically, fixed on the stage of the microscope *b* and connected with its ancillary devices.

The outlet tube *c* of the cell is connected with a vacuum pump *d* through a guard tube *e* of a capacity of 10 to 15 cm.^{3} to collect the used dye solution, and a three-way stopcock *f*. The latter can be used to cut out the vacuum pump as desired.

The dye solution to be circulated is in a burette *g*, which is connected by a rubber pipe *h* with a pipette *i*, the finely tapered point of which penetrates deeply into the feed tube *k* of the cell.

The inlet flow of the dye is adjusted so as to be slightly greater than the outlet flow. The excess solution drips slowly into a recipient *l* through a rubber tube *m* acting as a gutter, fitted over the inlet tube *k* of the cell and having a port through which the pipette *i* can be passed (see details in Figure 22).

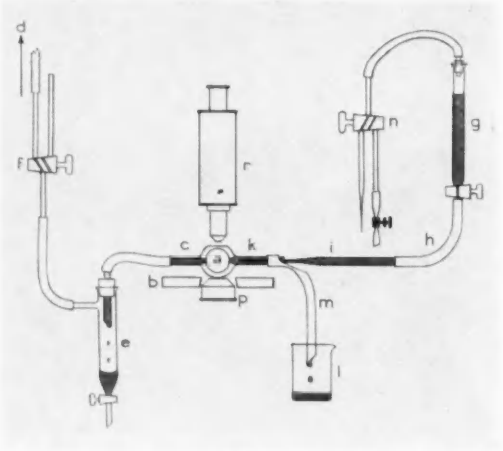


Fig. 21. Cell and its feed. Assembly as a whole.

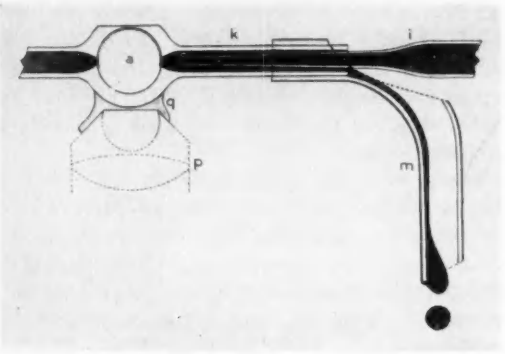


Fig. 22. Details of feed.

The three-way stopcock *n* connected with the burette *g* permits two different flows: a quick flow lasting only a short time (for washing out the inlet tube when the reagent is changed) and a slow continuous flow (for the normal supply of liquid to the cell).

4. *Changing the Reagent*

In a general way it is impossible to eliminate the dye solution or other reagents completely from the cell by passing air through the latter. A certain quantity of liquid surrounding the fiber always remains. Moreover, this method of operating has a great drawback: the fiber is suddenly displaced from its normal position and is projected with the remainder of the solution from one wall of the channel to the other by the air circulating in the channel.

To avoid these mechanical actions on the fiber, we change the reagent by causing one liquid to eliminate the other.

With the miscible liquids which we habitually use, this operation can be carried out without difficulty. The time during which combined action of the two reagents (the reagent to be eliminated and the eliminating reagent) on the fiber is possible, does not exceed a few seconds.

The operation is carried out as follows. The vacuum pump is cut out by means of the stopcock *f* (Figure 21) and the air pressure is equalized at both cell openings. The two ways of the stopcock are then blocked by turning the key by an angle of 90°. Thereupon the first solution is evacuated from the inlet tube of the cell. This is easily effected by blowing air into the tube with a drawn pipette. In this way the inlet tube is emptied of solution, but no air penetrates into the cell. The inlet tube is

washed, then filled with the second reagent which is introduced by means of a pipette connected with a burette (Figure 21). A few seconds (1 to 3 sec.) after the vacuum pump has been put into the circuit again, the new solution enters the cell and forces the first one out.

5. *Illumination of the Microscope*

To facilitate observation of the limit of penetration of the dye into the fiber and exact measurement of the depth of penetration, it is advisable to accentuate the contrast in the optical image if possible. Various devices can be recommended for this purpose, according to the following cases.

1. The use of contrast filters with maximum absorption in the range of wavelengths where the dye solution used gives *maximum transmission.*

Excellent results are obtained by using interferential filters. Red or yellow filters should be used when working with Chlorazol Sky Blue FF solutions.

2. In combination with the use of contrast filters, advantage can be taken of the dichroism of the dyed fibers.

For this purpose polarized light will be used. By turning the polarizer, the plane of vibration of the light is so directed in relation to the axis of the fiber that the best visibility of the "penetration front" is achieved.

3. Occasionally the best results are obtained by use of colored contrast illumination.

The simplest way of achieving such an illumination is to partially cover the condenser opening with an ordinary contrast filter. In this case the light is bicolor. The uncovered part of the condenser lets the white light through, which takes on the color of the dye used, while the part of the opening covered by the filter lets through light of the same color as the filter.

If Chlorazol Sky Blue FF is used as dye, the two contrast colors can be blue and yellow or blue and red.

This method is useful at times, because it is much easier to differentiate between two colors at low intensity than between two different intensities in an almost monochromatic light.

6. *Assembly and Disassembly of the Cell*

All the treatments of the fiber for which microscopic examination is not necessary (for instance, periodic extraction of the dye with pyridine and consecutive washing in water) can be carried out by immersing the male part of the cell (on which the fiber is fixed) in a recipient containing pyridine, water, or some other reagent.

The cell is assembled and disassembled in a basin filled with distilled water, the male part of the body of the cell being mounted or removed beneath the water. This prevents to the maximum any mechanical action on the fiber and any damage to it by friction and pressure between the two parts of the cell.

7. *The Differential Dyeing Test*

The cell containing a piece of fiber whose ends have been carefully cut (Figure 16, *e*) and assembled beneath the water is fixed on the stage of the microscope and connected with the ancillary apparatus shown in Figure 21. It is in contact with the condenser (*p* in Figures 21 and 22) through a drop of immersion oil (Figure 22, *q*).

First of all, the distilled water contained in the cell (see section "Changing the Reagent") is replaced by a solution of electrolyte of a concentration equal to the electrolyte concentration of the dye solution it is intended to use for dyeing (for instance, a 10 g./liter NaCl solution, when it is intended to dye with a solution containing 10 g. of pure dye and 10 g. NaCl per liter).

After a short impregnation (2 to 3 min.) of the fiber by the salt solution, the dye solution (*e.g.*, a solution of 10 g. pure Chlorazol Sky Blue FF and 10 g. of NaCl per liter is substituted for the said solution.

Observation under the microscope (Figure 21, *r*) begins at the moment when the dye solution is substituted for the electrolyte solution. The beginning of penetration ($t = 0$) is easily recognized by the coloration of the field of observation, quickly followed by darkening when the dye solution fills the cell (when the vacuum pump is turned on).

The penetration of the dye into the core of the fiber, clearly visible and very rapid at the start, commences immediately.

By means of an eyepiece micrometer the depth of penetration [the distance between the cut end of the fiber and the "penetration front" (Figure 1)], is measured at different intervals of time read off from a chronometer which has been set at the beginning of the dyeing. The results of the measurements are plotted on a graph similar to Figure 3.

When a certain number of measurements have been made, dyeing can be stopped.

The cell is dismounted (see paragraph "disassembly"), the male part carrying the fiber is washed in water to remove the remainder of the dye solution, then put in a recipient containing a 25% aqueous solution of pyridine (at the ordinary temperature). After 30-min. extraction, the cone is placed for 90 min. in running water (washing out the pyridine). It is then placed in a recipient filled with distilled water until the next dyeing is to be done. (We carefully avoided all drying of the fiber during the 37 days in which it was used).

The operations are then repeated as already described: the male part is replaced in the cell shell, the fiber is impregnated with electrolyte solution, then dyed.

All the tests described in Chapter B were made according to the technique we have just explained.

As a matter of fact, this technique is less complicated than it would seem from its description. There is no difficulty in applying it, provided that the necessary apparatus is available and that the work is carried out with proper care.

Summary

The authors have studied the kinetics of penetration of direct dyes into the core of viscose fibers by differential dyeing.

This study has been made according to a new method, described in detail and characterized by the use of a special microcell and of one and the same piece of fiber for a large number of repeated dyeings.

Examples of applications of the method are given, selected in various fields.

The new results obtained relate to

The influence of the concentration in salt, the concentration in dye, and of the nature of the dyes on the diffusion of the latter,

The migration of the dyes,

The diffusion of dyes in pre-dyed viscose fibers.

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Perkin Centennial Week

The deadline for hotel reservations for the Centennial Week (see TEXTILE RESEARCH JOURNAL, May 1956) is August 20. Hotel reservations will be handled solely through the New York Convention and Visitors Bureau, Inc., 90 East 42nd Street, New York 17, N. Y.

The Effect of Laundering, Mercerizing, and Simulated Vat Dyeing on the Properties of Partially Cyanoethylated Cotton

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Abstract

The effect of laundering, mercerizing, and simulated vat dyeing on the properties of partially cyanoethylated cotton was investigated. Cotton sheeting cyanoethylated to various nitrogen contents, from 2.2 to 6.4%, was subjected to laundering, mercerizing, or simulated vat dyeing. The samples were then analyzed for thread count, weight, and thickness and tested for breaking strength, elongation, tearing strength, abrasion resistance, air permeability, stiffness, moisture regain, heat resistance, and rot resistance. In addition, wrinkle recovery of the partially cyanoethylated and untreated cloth was determined.

Results of the study indicate that neither laundering, mercerizing, nor simulated vat dyeing seriously affects the usual textile properties of partially cyanoethylated cotton. The rot resistance and heat resistance of samples of more than 4% nitrogen content were not greatly impaired by these treatments; however, a sample of 3.2% N was not rot-resistant after these subsequent treatments.

AN investigation of the effect of laundering, mercerizing, and simulated vat dyeing on the properties of cyanoethylated cotton has been made to secure information on the properties of the material after it has been subjected to conditions which are often encountered during the finishing and use of a textile material. Such information is necessary in order to judge better the potential value of the fabric.

Some of the properties of cyanoethylated cotton have been described by Compton, *et al.* [3], and a more complete summary has been given by Grant, *et al.* [7] in a progress report of work on the research product at the Southern Regional Research Laboratory. These properties, however, refer to the original modified cotton. A paper by members of the Rhode Island Section of the AATCC [9], which describes effects of bleaching, dyeing, and resin finishing, has partially met the need for some of this information.

The present paper provides additional information on properties as affected by laundering, mercerizing, and vat dyeing. The usual textile tests, as well as heat resistance and rot resistance, were conducted on partially cyanoethylated cotton of various degrees of substitution, on a caustic-treated control, on untreated cotton, and on the aforementioned samples after being subjected to laundering, mercerizing, and simulated vat dyeing.

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Experimental

Fabrics

The fabrics used in this study included a boiled and bleached 48 × 48 cotton sheeting, weighing approximately 4.8 oz./yd.^{2}, referred to as the untreated; the same fabric treated with 2% sodium hydroxide solution was the control; and four partially cyanoethylated fabrics containing 2.2, 3.2, 4.2, and 6.4% N respectively, prepared from the same basic fabric in accordance with the method described by Daul, Reinhardt, and Reid [4]. This method consists essentially of padding the fabric to a 60% pickup of a solution of 2% sodium hydroxide and treating with acrylonitrile at 60° C. for various periods of time

until the desired degree of substitution is obtained. After this treatment, the samples are soured with a dilute acetic acid solution and thoroughly washed with water.

Aftertreatments

Laundering was performed in a wash wheel at 160° F. under conditions simulating Test 3A of the American Association of Textile Chemists and Colorists [1]. The ratio of soap to soda used was 5:2 in an amount sufficient to produce a running suds. At the end of each laundering the fabric was well rinsed with water, centrifuged, and ironed dry before being resubjected to washing. Samples were subjected to one, six, and twelve laundering cycles.

Mercerization was conducted at room temperature without tension using a 20% sodium hydroxide solution for 15 min. The cloth was then washed, soured with dilute acetic acid, washed with water until neutral, and ironed dry.

Vat dyeing was simulated by a bath in which no dye or sodium hydrosulfite was included. These components were omitted since the effect of the alkali was the principal factor under consideration. The fabric was treated in a wash wheel with an aqueous solution of 1 oz. of sodium hydroxide per gallon at 140° F. for 30 min. Afterward, samples were soured, rinsed until neutral, centrifuged, and ironed dry. (A more complete study of vat dyeing was reported after this work had been completed [6].)

Test Procedures

All tests were performed under standard textile test conditions, 70° F. and 65% relative humidity. Where suitable tests were available, the methods of the American Society for Testing Materials [2], were followed; otherwise the methods in Federal Specification CCC-T-191b [5] were used.

Strips ravelled to a count of 48 threads were used for the determination of breaking strength and elongation at break. Tearing resistance was determined by both the trapezoid and Elmendorf[2] pendulum methods. The Stoll Universal Wear Tester was used for both flex and flat abrasion measurements. Crease resistance was determined with the Monsanto Wrinkle Recovery Tester, the Tinius-Olsen Stiffness Tester was employed for stiffness measurements, and the Gurley Permeometer for air permeability. Weight determinations were made on five specimens totalling 20 in.^{2} of fabric.

In addition to these usual textile tests, the breaking strength after exposure to heat and soil burial was determined. The heating was carried out in a forced draft oven at 160° C. for three and seven days. The soil burial exposures were conducted in accordance with A.S.T.M. procedures; pH of the soil was 6.8 to 7.5.

[2] The mention of trade names and firms does not imply their endorsement by the Department of Agriculture over similar products or firms not mentioned.

Discussion and Results

Results of tests of the untreated and partially cyanoethylated fabric both before and after laundering, mercerizing, and simulated vat dyeing are shown in Tables I and II. The effects on structure are summarized in Table I, while Table II gives the physical properties of the fabrics.

The properties of the partially cyanoethylated cotton cloth prepared for this study are in good agreement with those previously reported from this laboratory [7]. When they are compared with those of the untreated cotton, it will be noted that the breaking strengths are essentially the same, but thread count, weight, thickness, elongation, stiffness, and resistance to flat abrasion were increased. Tearing strength, flex abrasion, crease resistance, air permeability, and moisture regain decreased with increase in nitrogen content.

Structural Properties

A certain amount of shrinkage and thickening of the fabric takes place as a result of the cyanoethylation reaction as evidenced by the higher thread count and greater thickness. From the values obtained, the amount of shrinkage was calculated as 9.5, 11.2, 16.1, and 23.4% for the 2.2, 3.2, 4.2, and 6.4% N samples, respectively. The control shrank 9.5% as a result of the dilute caustic treatment. None of the aftertreatments had appreciable effect on the thickness of the fabric. The thread count also was unaffected by the laundering and dyeing procedures, but it was increased by mercerization. This would be expected since no tension was applied during the mercerization and the fabric was free to shrink in the strong caustic.

The weight of the fabric increased with the degree of substitution of cyanoethyl groups. Changes in

the weight of the cloth with aftertreatments may be attributed to shrinkage.

Moisture Regain

The moisture regain of cotton is reduced by cyanoethylation, the reduction being progressive as the substitution increases. As is shown in Table I, the moisture regain is almost unaffected by laundering and simulated vat dyeing. Mercerization increased the regain of the lower substituted samples but did not change the values for the 4.2 and 6.4% N samples.

Breaking Strength

Laundering through 12 cycles apparently has little effect on the breaking strength of partially cyanoethylated cotton cloth whereas the untreated and control appear to have undergone a slight reduction. Vat dyeing also has little effect but there appears to be a slight lowering of the breaking strength, especially for the fabric containing 6.4% N, the untreated and the control. Mercerization increases the strength of cyanoethylated cotton considerably in the lower ranges of substitution but appears to have decreased the strength of the 4.2 and 6.4% N samples.

Elongation at Break

Cyanoethylation increases the elongation at break of cotton cloth; laundering and simulated vat dyeing cause an additional increase. The mercerization effect has been to increase the elongation of the untreated and lower substituted fabrics; but there is little, if any, effect on the two highest substituted cottons. Variations in elongation seem to correlate fairly well with shrinkage as determined by changes in thread count.

Tearing Strength

The tearing strength of untreated cotton fabric, determined by the trapezoid method, was somewhat

TABLE I. Effect of Laundering, Mercerizing, and Simulated Vat Dyeing on the Structural Properties and Moisture Regain of Untreated and Partially Cyanoethylated Cotton Fabrics

Property	Untreated	Control	Cyanoethylated cotton			
			2.2% N	3.2% N	4.2% N	6.4% N
Thread count, warp×filling						
Original	49×49	52×51	52×51	53×51	54×53	57×55
Laundered						
1×	52×53	53×52	53×52	54×52	55×53	56×56
6×	54×53	54×53	53×51	54×53	55×53	57×55
12×	54×53	53×52	53×52	54×53	55×54	56×56
Mercerized	61×58	60×57	59×58	59×57	55×53	55×54
Vat dyed (simulated)	52×51	53×52	53×51	54×52	54×53	56×56
Weight, oz./yd.^{2}						
Original	4.8	5.0	5.7	5.7	6.4	7.6
Laundered						
1×	5.3	5.3	5.7	5.9	6.4	7.8
6×	5.5	5.2	5.6	6.1	6.5	7.9
12×	5.6	5.5	5.5	6.3	6.7	8.1
Mercerized	6.6	6.6	7.1	6.9	6.4	7.4
Vat dyed (simulated)	5.0	5.3	5.5	6.0	6.4	7.8
Thickness, $\times 10^{-3}$ in.						
Original	14.7	15.4	16.0	16.7	17.3	18.3
Laundered						
1×	16.6	16.8	16.7	16.8	17.1	18.8
6×	17.1	16.2	16.6	17.2	17.1	18.6
12×	17.3	16.8	16.3	17.6	17.4	18.3
Mercerized	17.3	17.6	18.1	17.5	17.1	17.5
Vat dyed (simulated)	16.3	16.1	15.8	16.5	17.4	18.6
Moisture regain, %						
Original	6.6	7.0	5.8	5.3	4.3	3.4
Laundered						
1×	6.6	6.8	5.4	4.9	4.1	3.3
6×	6.7	6.8	5.9	5.1	4.1	3.5
12×	6.8	6.8	5.8	4.9	4.2	3.3
Mercerized	8.7	8.8	8.1	6.8	4.3	3.5
Vat dyed (simulated)	5.7	6.6	5.9	5.3	4.5	3.7

improved by laundering, simulated vat dyeing, and especially by mercerization. These effects were about the same on the control samples. In general, cyanoethylated cotton fabric also showed slight increases of the tear strength on repeated launderings, and the higher substituted samples on simulated vat dyeing. This aftertreatment reduced the tearing strength of the samples of fabrics of 2.2 and 3.2% N. Mercerization produced a significant increase in tear resistance.

Tearing strength measured by the Elmendorf method showed a progressive decrease as the substitution of cyanoethyl groups was increased. Whereas the strength of the untreated and control was decreased by laundering, that of the cyanoethylated samples increased. This increase became greater with the number of laundry cycles. Mercerization produced an improvement in tearing strength of cyanoethylated samples, but vat-dyed (simulated) samples were practically unaffected.

Abrasion Resistance

In accord with previous reports [7], the resistance of cyanoethylated cotton to flat abrasion is superior to that of untreated cotton. This was evident even in aftertreated samples except for a slight discrepancy in the samples subjected to six laundry cycles. The improvements in flat abrasion resistance followed the increase in substitution of cyanoethylated samples, except for the sample of 3.2% N content.

Flex abrasion of partially cyanoethylated cotton is considerably lower than that of the blank or the control. Laundering, however, caused a surprisingly large increase in flex abrasion resistance. The values increased with the number of laundry cycles. On the 6- and 12-cycle samples, the values were considerably greater than those of the blank or the control. Mercerization caused a great increase in the flex abrasion resistance of the blank, control, and the cyanoethylated sample of 2.2% N. The abrasion resistance of the 3.2% N sample increased slightly,

TABLE II. Effect of Laundering, Mercerizing, and Simulated Vat Dyeing on the Physical Properties of Untreated and Partially Cyanoethylated Cotton Fabrics

Property	Untreated	Control	Cyanoethylated cotton			
			2.2% N	3.2% N	4.2% N	6.4% N
Breaking strength, lb.						
Original	56.8	55.6	55.6	57.2	56.9	54.7
Laundered						
1×	51.4	52.2	57.2	54.8	57.5	55.7
6×	53.1	53.4	55.4	56.1	57.1	57.3
12×	48.2	50.7	54.5	54.4	54.0	56.5
Mercerized	61.7	58.5	60.4	59.4	53.4	52.3
Vat dyed (simulated)	52.9	52.2	55.4	55.4	54.2	51.5
Elongation at break, %						
Original	16.0	18.4	17.7	17.0	22.0	24.8
Laundered						
1×	21.7	21.7	17.7	18.3	20.0	26.0
6×	23.0	20.7	19.3	19.7	21.3	28.3
12×	22.3	22.3	20.3	22.0	22.7	26.0
Mercerized	33.0	35.3	34.7	29.0	21.7	22.3
Vat dyed (simulated)	22.7	18.7	19.0	19.3	20.7	27.3
Tearing strength, trapezoid, lb.						
Original	8.2	9.2	7.0	7.7	6.8	6.8
Laundered						
1×	9.7	8.4	7.6	7.4	7.7	8.2
6×	9.2	8.3	7.5	7.3	7.7	7.6
12×	9.4	8.5	7.7	7.2	8.2	8.7
Mercerized	14.3	15.1	14.9	10.5	8.0	7.6
Vat dyed (simulated)	9.0	9.1	6.8	6.5	6.9	7.5
Tearing strength, Elmendorf, lb.						
Original	4.8	5.6	3.3	2.5	2.4	2.2
Laundered						
1×	4.6	4.8	3.1	2.8	3.0	2.9
6×	4.6	4.2	3.4	3.1	3.3	2.9
12×	4.5	4.1	3.8	3.3	3.4	3.3
Mercerized	6.3	6.3	5.3	4.3	2.9	2.5
Vat dyed (simulated)	5.5	4.9	3.6	2.6	2.4	2.2

whereas the higher substituted samples were unaffected by mercerization. Simulated vat dyeing seemed to have little effect on the flex abrasion resistance of the cyanoethylated samples and controls.

Air Permeability

As would be expected from the progressive closing of weave by shrinkage, increase in weight and thickening of the fibers with increase in substitution, air permeability of partially cyanoethylated cotton is reduced in proportion to the degree of substitution. That this is due to the physical change in the textile rather than the chemical constitution is exemplified in Figure 1. These data show that the air permeability is a direct function of the weight of the fabric regardless of its nitrogen content or aftertreatment.

Stiffness

Cyanoethylation causes some stiffening of the fabric; however, the hand as judged subjectively is not appreciably changed except for the 6.4% N sample, which is noticeably stiffened.

Stiffness was increased with repeated launderings which may be explained by shrinkage. Mercerization caused an increase in the bending moment of the 2.2 and 3.2% N samples but reduced that of the 4.2 and 6.4% N samples. Samples vat dyed also showed a decrease in stiffness.

Heat Resistance

As shown in Table III, and in agreement with previous findings [3, 7], the heat resistance of the partially cyanoethylated fabrics is superior to that of the untreated fabrics. Laundering, mercerization, and simulated vat dyeing all lower the heat resistance of both the untreated and partially cyanoethylated fabrics. However, aftertreated cyanoethylated cotton remains greatly superior to similarly treated blank and control cloth.

TABLE II. (Continued)

Property	Untreated	Control	Cyanoethylated cotton 2.2% N	3.2% N	4.2% N	6.4% N
Abrasion, flex, cycles						
Original	964	1380	336	219	283	230
Laundered						
1×	1480	1780	506	294	514	446
6×	1541	1225	1649	2008	2146	2464
12×	1330	1421	1989	1540	2136	2656
Mercerized	2446	2180	2411	360	283	215
Vat dyed (simulated)	1274	1108	236	208	253	230
Abrasion, flat, cycles						
Original	69	90	94	88	124	135
Laundered						
1×	57	57	105	83	78	126
6×	74	56	64	61	102	112
12×	61	53	81	68	80	141
Mercerized	77	91	87	93	87	109
Vat dyed (simulated)	65	65	66	82	97	113
Air permeability, ft.³/min./ft.²						
Original	123.0	70.0	48.3	46.4	25.4	11.7
Laundered						
1×	48.9	53.0	45.2	32.2	24.7	10.3
6×	47.8	54.0	41.3	29.5	22.9	11.7
12×	42.1	47.4	36.3	26.4	18.2	13.4
Mercerized	21.8	19.3	22.1	23.0	18.3	16.3
Vat dyed (simulated)	52.5	55.0	46.9	28.6	24.9	11.8
Stiffness, $\times 10^{-4}$ in.-lb.						
Original	5.2	4.9	5.4	7.2	6.8	12.2
Laundered						
1×	5.3	4.8	6.2	6.3	6.0	11.6
6×	5.6	5.8	5.6	6.4	6.3	9.7
12×	6.0	6.2	6.8	7.0	8.0	13.3
Mercerized	11.4	16.2	16.6	17.5	6.4	6.9
Vat dyed (simulated)	5.1	5.2	4.7	5.1	6.4	10.4
Wrinkle recovery angle, degrees						
Original	95	88	98	93	76	70

Rot Resistance

As has been previously shown, a nitrogen content of about 4% is necessary for good rot resistance. Samples with 4.2 and 6.4% N withstood 12 weeks' soil burial with excellent retention of original breaking strength, even when tested after laundering, mercerizing, or simulated vat dyeing. The sample of 3.2% N content which is on the borderline of good rot-resistance retained 96 and 70% of its original breaking strength after 6 and 12 weeks' soil burial, respectively, but with one exception, failed completely when aftertreated. The sample buried for 6 weeks after one laundry cycle retained 50% of its original breaking strength. Complete results of this study are shown in Table IV.

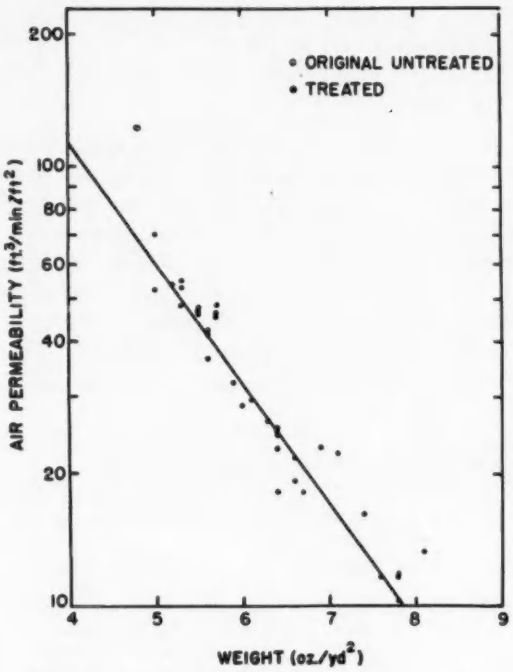

Fig. 1. Air permeability versus weight of fabric.

Nitrogen Content

The nitrogen content of cyanoethylated samples was practically unchanged by the aftertreatments studied. No loss occurred on laundering, and samples lost only 0.2 to 0.5% nitrogen on mercerization and simulated vat dyeing. The concentration of caustic used in the simulated vat dyeing, 1 oz./gal. of water (or about 0.75%) is below that which has been shown by Mazzeno, *et al.* [8], to cause only a small amount of hydrolysis or cleavage of cyanoethyl groups at 60° C. (140° F.).

Summary and Conclusions

A series of partially cyanoethylated cotton fabrics varying in nitrogen content from 2.2 to 6.4% was prepared to determine the effects of laundering, mercerizing, and vat dyeing. The properties of the modified cotton were in keeping with those previously reported.

TABLE III. Effect on Heat Resistance (160° C.) of Laundering, Mercerizing, and Simulated Vat Dyeing of Untreated and Partially Cyanoethylated Cotton Fabrics

	Breaking strength retained (%)					
			Cyanoethylated cotton			
	Untreated	Control	2.2% N	3.2% N	4.2% N	6.4% N
3 Days' exposure						
Original	25	21	45	60	60	67
Laundered						
1×	14	15	39	45	64	65
6×	13	15	34	38	48	32
12×	19	15	29	27	42	40
Mercerized	19	15	44	36	48	44
Vat dyed (simulated)	17	17	54	38	67	35
7 Days' exposure						
Original	11	10	25	30	29	18
Laundered						
1×	11	10	21	25	31	26
6×	8	9	18	18	24	13
12×	7	8	16	16	20	14
Mercerized	9	10	18	22	23	13
Vat dyed (simulated)	10	9	20	22	26	13

TABLE IV. Effect on Rot Resistance of Laundering, Mercerizing, and Simulated Vat Dyeing of Untreated and Partially Cyanoethylated Cotton Fabrics

	Breaking strength retained (%)					
			Cyanoethylated cotton			
	Untreated	Control	2.2% N	3.2% N	4.2% N	6.4% N
6 Weeks' soil burial						
Original	*a*	*a*	*b*	96	97	103
Laundered						
1×	*a*	*a*	*a*	50	99	99
6×	*a*	*a*	*a*	*b*	98	98
12×	*a*	*a*	*a*	*b*	84	98
Mercerized	*a*	*a*	*a*	*b*	90	97
Vat dyed (simulated)	*a*	*a*	*a*	*b*	100	96
12 Weeks' soil burial						
Original	*a*	*a*	*a*	70	94	100
Laundered						
1×	*a*	*a*	*a*	*b*	96	96
6×	*a*	*a*	*a*	*b*	89	95
12×	*a*	*a*	*a*	*b*	92	91
Mercerized	*a*	*a*	*a*	*a*	90	98
Vat dyed (simulated)	*a*	*a*	*a*	*b*	98	96

a: Completely deteriorated.
b: Not completely deteriorated, but of no measurable strength.

In general, this study has shown that laundering, mercerizing, or simulated vat dyeing will not seriously affect the serviceability of partially cyanoethylated cotton, provided that the original properties of the modified cotton are acceptable. A sample cyanoethylated to about 4% N stands up well to these aftertreatments. Even rot- and heat-resistance of samples of this degree of substitution are not seriously impaired by laundering, mercerizing, or simulated vat dyeing. A sample of 3.2% N, however, was no longer rot-resistant after these treatments.

Launderings were carried out on the cyanoethylated samples and controls. No serious damage was observed; in fact the most striking effect of laundering is seen in the improvement of flex abrasion.

Mercerization produced results which depended upon the degree of substitution of the cyanoethylated cotton. Samples with nitrogen contents of 2.2 and 3.2% followed the usual pattern of mercerization, as indicated by the changes in properties. The more highly substituted samples, 4.2 and 6.4% N, exhibited a less marked effect, and in many cases, the results were the opposite of those produced on the less substituted samples. Surprisingly, mercerization did not destroy the rot resistance of the 4.2% sample, which withstood soil burial for 12 weeks.

Simulated vat dyeing had about the same effect on most properties as one laundry cycle.

Acknowledgment

The authors wish to extend their thanks to Ruby K. Worner and Laurence W. Mazzeno, Jr. for helpful suggestions and aid in preparing the manuscript, and to Julian F. Jurgens for nitrogen analyses.

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The Effect of Aluminum Powder on the Heat Insulation of Goose Down

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Abstract

The effect on the thermal insulation value of goose down was examined when different amounts of aluminum powder were added by dusting. At low density considerable improvement was found to be possible.

Introduction

The investigation described below was undertaken to see how much the insulation of goose down could be improved by dusting with aluminum powder. Finck [1] had found that the thermal conductivity of kapok could, by such treatment, be reduced by 15.5% and of asbestos by 18%. Kennedy [2], by incorporating a filler in styrofoam, had noted an improvement of 20% and White [4], working with silica aerogel, had observed a large improvement by adding silicon. No results on the effect of making goose down more reflective seemed to be available although that material, on account of the large volume of air space it contains, is outstandingly suited to respond to such treatment. Furthermore, because of its extreme lightness, down in combination with textiles has possibilities for insulating the human body against cold which few other materials possess.

Apparatus

The apparatus used to measure the thermal insulation value was the hot-plate apparatus used at the National Research Council, Ottawa, for measuring the insulation of clothing and blankets and has been described by Larose [3]. The samples were made up by putting the loose material into a wooden frame 1 in. in thickness and 17 by 18 in. in area. The frame was faced on either side with brown paper. The volume occupied by the down was thus 5012 cc.

The insulation values have been expressed in clo units, the unit used in measuring the insulation of clothing. (A clo value of insulation R may be converted into a B.T.U./hr./sq. ft./° F. value of conductance C by means of the equation $CR = 1.14$.)

Experimental Procedure and Results

The wooden frame was filled with 14 g. of goose down, and the thermal insulation was measured. The down was then taken out and mixed with 10 cc., approximately 6 g., of aluminum powder; the mixture was then returned to the frame and measured again. This procedure was repeated, adding another 10 cc. of powder, and then repeated again, adding a third measure of powder. The effect of adding powder while the amount of down was kept constant was thus observed. The first measure of powder caused a large increase in insulation, the second much less, and the third no improvement.

The same series of tests was carried out again except that 28 g. of down were used. Then a third series of tests was conducted using 42 g. of down. The same type result was obtained in each case.

The results are plotted in Figure 1. At a density value of about 8.4×10^{-3} g./cc. it will be observed that adding aluminum powder improved the insula-

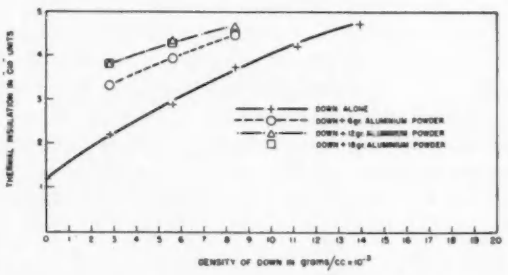
THERMAL INSULATION IN CLO UNITS
DOWN ALONE
DOWN + 6gr. ALUMINUM POWDER
DOWN + 12gr. ALUMINUM POWDER
DOWN + 18gr. ALUMINUM POWDER
DENSITY OF DOWN IN grams/cc. × 10⁻³

Fig. 1. Curves showing the effect on the thermal insulation of goose down at various densities caused by adding aluminum powder.

tion comparatively little. It is to be expected that at higher densities the effect of the powder would be small because air spaces are essential if heat insulation is to be effected by reflexion. As the work was undertaken primarily to ascertain how beneficial dusting could be, tests at higher density than those plotted on the graph were of little interest, because the heat transfer would be affected less and less by the reflexion of heat from the tiny specks of metal on the fibers of the down, the more the air spaces were eliminated by compression. In the limit one might imagine two of these highly conducting specks in contact and actually helping rather than hindering heat transfer.

At low densities the beneficial effect of dusting was very marked. There was a limit, however, to the lightness of packing which was permissible because the frame had to be filled with down to stop convection currents. This limit appears to be somewhere near 2.8×10^{-3} g./cc. As aluminum powder is so heavy in comparison with goose down, dusting did not improve the insulation value per unit of weight. The results in this respect were somewhat disappointing.

Chicken feathers pack much more closely than down and were found to respond badly to the dusting treatment.

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Relation between Grab Strength and Strip Strength of Fabrics

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WHEN testing the tension of woven fabrics, mainly two routine methods are applied, viz.: the grab method and the raveled-strip method. In both cases breaking strength and the extensibility are determined, and normally a greater breaking strength is obtained with the grab method than with the raveled-strip method for the same widths inserted in the clamps.

There are two reasons for using the grab method. One is that the test is simple to perform by routine, *inter alia* the test preparation is simple. The other is that a method is achieved which corresponds more closely than the raveled-strip method to load applications in practical use. Only in exceptional cases is stretching of a fabric performed on a sample of the same width as the part attacked by the tensile forces. However, as the determination of practical cases is subjective, it is of great importance to find a relation between strip and grab strength so that the measuring results of the methods can be compared numerically. So far, the relations suggested have been quite empirical and of rather small range applicable to certain types of fabrics, as for instance in the early paper by Walen in 1916 [4].

In order to get a clear idea as to the distribution of forces in connection with the grab method, we assume that a fabric is stretched in the warp or weft direction with two clamps, as shown schematically in Figure 1.

Figure 1*a* shows the fabric before stretching, with warp and weft threads symmetrically arranged. In Figure 1*b*, the clamps have been drawn apart. The

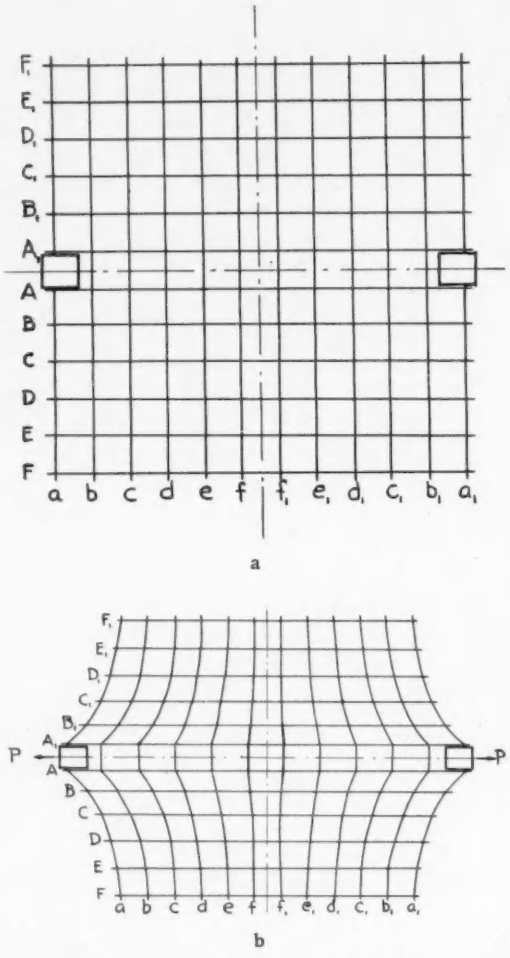

Fig. 1. Fabric specimen stretched threadwise, clamps narrower than the distance between two threads; *a*, before stretching, *b*, under stretching.

threads A and A_1 will be most elongated, and as a rule, they determine the elongation at break. By means of the transverse threads a and a_1, B is stretched by A, C by B, etc. The difference between the breaking strength P of the sample and the strength breaking A and A_1 will therefore be the sum of the forces elongating B and B_1, C and C_1, etc.

From Figure 1*b* the qualitative assumption can be made that the additional force exceeding the force which is required for breaking A and A_1 increases with the elongation under otherwise similar conditions. The larger the elongation, the greater the number of the side threads that will be stretched. Furthermore, it should, *inter alia*, depend on the extensibility in the system *a*, *b*, *c*, . . . and on the number of threads in both systems. Also the design should have an influence, in which a harder construction can be expected to give greater additional strength than a softer one, *e.g.*, a plain weave compared with a twill with the same number of threads. Finally, the additional force should depend on the form of the load-elongation curve.

Without dealing further with the factors mentioned, we now assume that the small clamps are exchanged for broad clamps, as shown in Figure 2. It can then be assumed that the breaking force is composed of two parts, *viz.*, the strip breaking force corresponding to the clamp width and the additional force which is carried by side threads corresponding to B, C, D . . . and B_1, C_1, D_1 . . . in Figure 1.

The conclusion will be that if for a fabric grab and raveled-strip tests are performed with the same width of clamps, a difference will occur equal to the value which would be obtained for a grab rupture with a very narrow clamp. The breaking strength for a strip test specimen within certain limits of the ratio specimen length/width should be proportional to the clamp width. The grab test should give values which lie just as much above the breaking

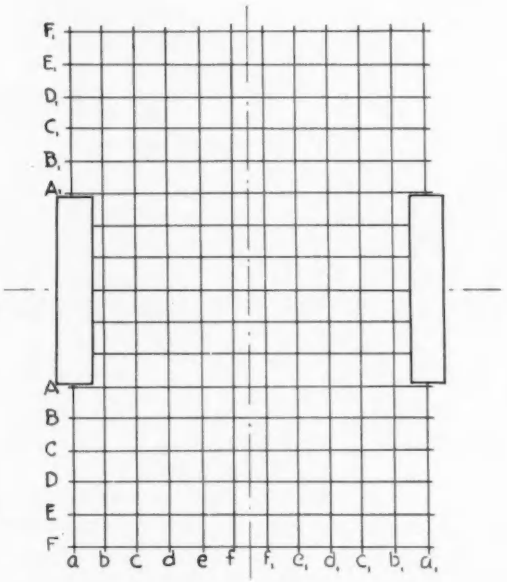

Fig. 2. Fabric specimen with broad clamps.

values of the strip test specimen as the breaking value of grab tests with the clamp width zero. This is schematically shown in Figure 3.

In order to try the reliability of the theory, a continuous filament rayon fabric was tested according to both the grab method and the raveled-strip method. The grab method was performed in specially manufactured clamps in which the width of the clamps could be varied (Figure 4).

The design of the fabric is seen in Figure 5. The warp and the weft consisted of viscose rayon 120/30 den. The number of ends was 76.7 and the picks 43.5/cm.

The tests were performed in an Instron Tensile Testing Machine and the following conditions were applied.

The dimensions of the grab method, see Figure 6.

Width of the strip $b + 1$ cm.; the strip raveled to b cm.

The distance between the clamps at the start of the test 7.5 cm.

Rate of elongation 400%/min.

Tests in standard atmosphere.

The results are seen in Figure 7, in which the warp and weft strengths have been plotted against the width b in the specimen. Parallel straight lines are obtained in accordance with the conclusions which have been theoretically drawn. Each point

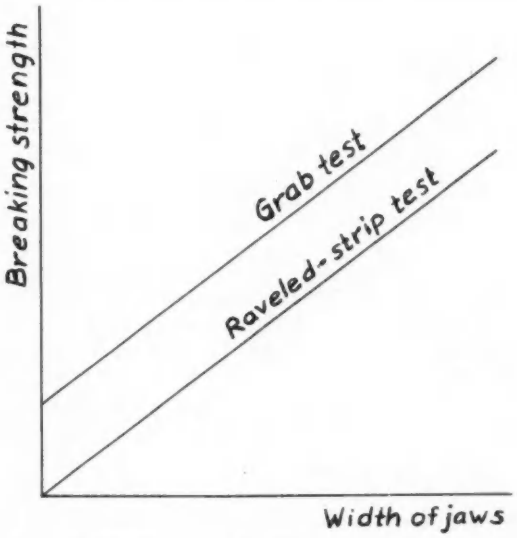

Fig. 3. Theoretical relation between breaking strength and width of jaws.

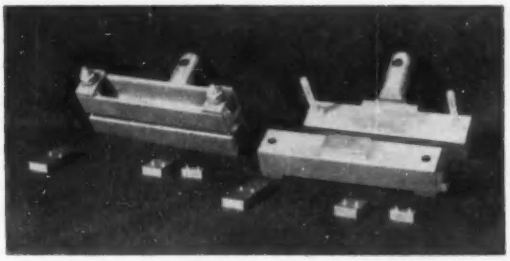

Fig. 4. Used clamps.

Fig. 5. Design of the tested viscose rayon fabric.

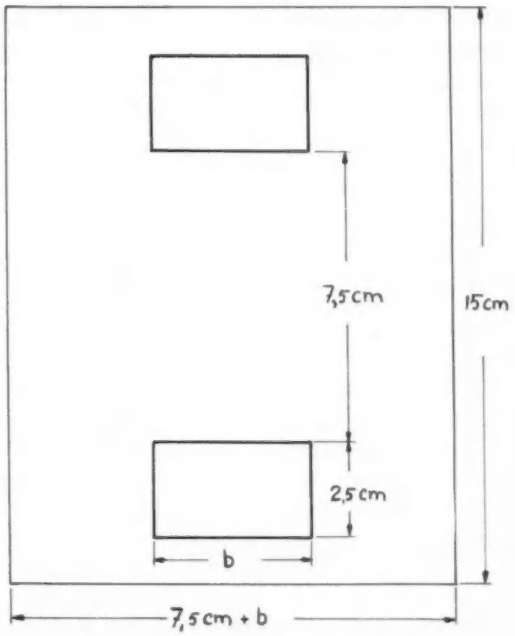

Fig. 6. Dimensions of the grab specimen.

in the diagram has been based on 1–3 measurings. The scattering was very small between the individual measuring values owing to the character of the fabric.

If the distance between the clamps were zero, a very small number of yarns would be elongated outside the clamps. Therefore, it can be assumed that in this case the grab method would give the same result as the raveled-strip method. By increasing the distance, the influence of the side threads would increase. This involves a subjective moment when determining the strength of a fabric by means of the grab method.

Figure 8 shows how the grab strength for a width of 3 cm. varies for the weft with the distance between the clamps. The relative rate of elongation has in all cases been the above indicated, *viz.*, 400%/min.

When comparing values obtained by means of grab and raveled-strip methods, the following, according to the above, would be obtained:

$$G_{ba} = R \cdot b/b_R + g_a \qquad (1)$$

G_{ba} = breaking strength for a grab specimen with a clamp width b and clamp distance a.

R = breaking strength for a raveled-strip specimen of the width b_R.

g_a = the power absorption of the side threads on the clamp distance a.

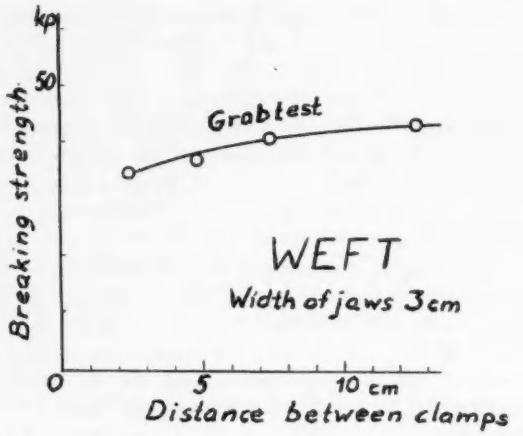

Fig. 8. Measured breaking strength by varying distance between clamps.

In order that the grab method can be used for calculating the R value and the g value, it is necessary that the grab method be used for at least two clamp widths, for instance, b and $2b$, where $b = 1$ in. which is normal for this method. If the width of the clamps for the raveled strip method is b, the following will be obtained from (1):

$$G_1 = R + g$$
$$G_2 = 2 \cdot R + g \qquad (2)$$

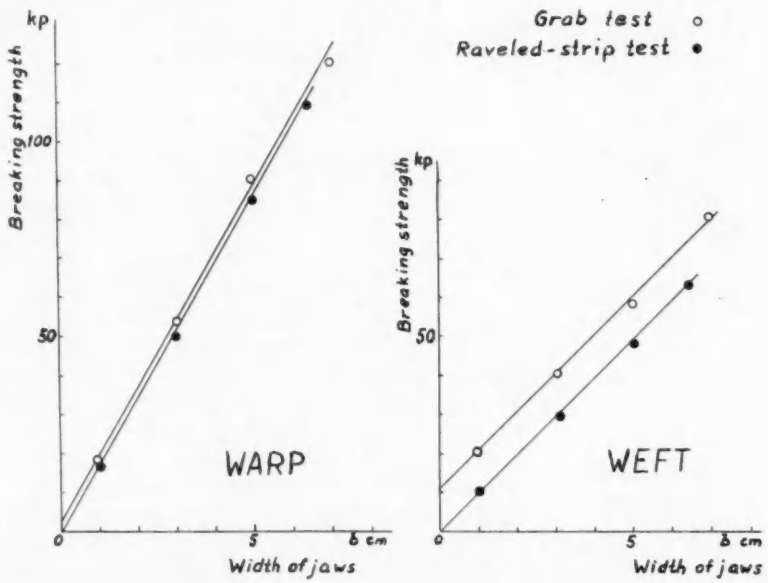

Fig. 7. Measured breaking strength by the constant distance 7.5 cm. between the clamps.

and if these are combined,

$$R = G_2 - G_1$$
$$g = 2 \cdot G_1 - G_2 \qquad (3)$$

The raveled-strip strength can also be obtained, as was mentioned in connection with the influence of the distance between the clamps, by performing the grab at a distance of zero. This procedure, however, is not recommended, partly because of technical difficulties when carrying out experiments, and partly because of the influence of the fiber length being too great for fabrics of staple fibers.

Under practical conditions it is only the American testing methods which are of a kind similar to the grab and raveled-strip methods. The distance between the clamps in both methods is 3 in., the width of the clamps is 1 in., and the speed of elongation, 12 in./min. Comparisons can be made, therefore, according to the method indicated above. If the breaking strength is to be compared with the raveled-strip strength at other conditions, *e.g.*, the Swedish standard, the comparison can not be made so directly. In this standard (strip method) the distance between the clamps is 20 cm., and the width 5 cm. and the rate of elongation so adjusted that ruptures are obtained after 60 ± 10 sec. stretching. The greatest difference between the grab method and the raveled-strip method exists in the rate of elongation. The grab test, therefore, gives an addition of power g which is higher than would be obtained according to the method in Formula 3. This extra addition depends on the breaking time being much shorter for the grab method than for the raveled-strip method. Certain additions can also be obtained when the tests are performed in a pendulum testing machine, especially if different measuring ranges must be used to test the grab and raveled-strip strength.

Attempts are being made in the international standardization work to establish a standard rate of elongation for both methods. Probably the rate of elongation will be selected especially for each material; *i.e.*, this will be done on the basis of a certain breaking time and the rate of elongation will then be selected so that this time will be obtained. It is assumed that the breaking time 60 ± 10 sec. will be selected. From the testing point of view it would have been preferable to have the same specific rate of elongation for all materials.

If the grab and raveled-strip methods are based on the same testing conditions, but 1 in. clamps are used for grab testing and the raveled-strip width is equal to 5 cm., the raveled strip force, according to the theory given above, can be calculated from the following formulas.

$$R = 2.03 \cdot (G_5 - G_{1\text{ in.}})$$
$$g = 2.03 \cdot (G_{1\text{ in.}} - 0.508 \cdot G_5) \qquad (4)$$

The grab strength has been determined at the two clamp widths 1 in. and 5 cm.

The above described investigations and conclusions refer to a fabric which consists of continuous filament yarns. The conclusions with regard to the influence of the distance between the clamps, for instance, thus are specific for fabrics of this kind. With respect to the addition of force when grab testing, the conclusions would be valid in general, irrespective of any inferior disturbances in boundary conditions. In connection with this investigation, the additional force in relation to extensibility and fabric construction factors has not been investigated. The importance of the extensibility has previously been shown empirically by Bernskiöld [1, 2] and Jameson, and others [3]. These two investigations have shown that factors other than the extensibility, actuate the extent of the additional force. This is also shown in Figure 7. The weft gives a higher additional force than the warp despite its extensibility being lower, 20.4 and 23.4%, respectively, and despite the number of threads being less for the weft than for the warp.

It can be assumed that both the grab method and the raveled-strip method will be used in the future to a great extent. As both methods will serve as a basis of specifications, it should be interesting to further investigate the relation between the additional power in connection with grab testing, and the fabric construction factors. Irrespective of this, a possibility has been shown in this paper to correlate specifications based on both methods in a given fabric. Thus, it is more possible to determine to what extent the grab method is more appropriate than the raveled-strip method. In certain cases it may be necessary to test one and the same fabric for one purpose by the grab method and for another purpose by the raveled-strip method. It is also plausible that the grab method in special cases should be performed with other clamping distances than those now used.

Summary

From a theoretical point of view, according to Figures 1 and 2, a relation between breaking strength by raveled-strip test and grab test is stated and illustrated in Figure 3. The breaking strength by grab test should differ from the strength by strip test of the same width by a constant value independent of the width of the clamps. It is also stated that the difference should vary when the distance between the clamps is altered, so that by decreasing the distance the difference is also decreased, being zero when the distance is zero at equal width of jaws for the two test methods. The statements are shown to be in very good agreement with tests performed on a continuous filament viscose rayon weave.

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Manuscript received January 18, 1956.

Standards on Textile Materials

A new edition of ASTM Standards on Textile Materials revised as of January, 1956, is now available. Eleven new tentative methods of test are included relating to warp knit fabrics, pilling propensity of fabrics, test for wide elastic fabrics, abrasion resistance of yarns, absorbency time and absorptive capacity of nonwoven fabrics, analysis of asbestos-glass fiber textile materials, maturity of cotton fibers, spun and filament yarns made wholly or in part of man-made organic base fibers, and stiffness of fabrics. Several methods of test and specifications in the previous compilation have been revised.

Orders should be sent to American Society for Testing Materials, 1916 Race Street, Philadelphia 3, Pa. Price for single copies, $5.75. To ASTM Members, $4.40.

Letters to the Editor

Short communications in the form of Letters to the Editor are intended to provide prompt publication of significant new research results and to permit an exchange of views on papers previously published in the JOURNAL. These communications are not submitted to formal review as are research papers, and the editors do not assume any share of the author's responsibility for the information given or the opinions expressed. When work previously published in the JOURNAL is the subject of critical comment, the authors of the original paper are given an opportunity to submit a reply, which will be published concurrently when possible.

Iodine Sorption as an Index of Fiber Crystallinity

BRITISH CELANESE LIMITED
Research Laboratories
Putteridge Bury
Nr. Luton (Beds.), England
February 3, 1956

To the Editor
TEXTILE RESEARCH JOURNAL

Dear Sir:

The recent letter by Chitale [1] on this topic recalls some hitherto unpublished experiments by the writer which tend to cast doubt on the iodine sorption technique, and especially on its application to cellulose acetate [2].

Secondary cellulose acetate film was immersed in aqueous iodine–potassium iodide solution, then washed to remove excess solution, and examined spectrophotometrically in the region 360 to 500 mμ. The visual appearance of the film was typical of the "brown" solutions which are given by iodine in electron-donor solvents and are characterized by an absorption maximum at approximately 470 mμ [4]; the absorption spectrum of the film, however, showed no maximum but instead a steadily increasing absorption toward the lower wave lengths characteristic of the iodinium ion I_3^-. Since this ion might have been absorbed by the film directly from the iodine-iodide solution, another sample of film was placed in a "blue" solution of iodine in carbon tetrachloride, which contains only the molecular species I_2. After washing in carbon tetrachloride, the film again showed only the absorption spectrum characteristic of I_3^-.

Solutions of iodine in acetone also show the I_3^- spectrum, and the presence of the ion is attributed by Hildebrand to iodination of the solvent [3]:

$$CH_3COCH_3 + I_2 \rightarrow CH_3COCH_2I + HI$$
$$HI + I_2 \rightarrow HI_3$$

Similarly, the appearance of I_3^- in cellulose acetate may be attributable to iodination of acetyl groups.

The iodine concentrations of the solutions used in the experiments were approximately 0.01%, and the films were immersed in them overnight at room temperature. In the iodine sorption test, the concentration of iodine is much higher and the time of immersion much shorter. Attempts to measure the absorption spectra of cellulose acetate film subjected to the test conditions failed because the resulting optical densities were too high. Nevertheless it seems reasonable to suspect that iodination as well as physical sorption may occur under these conditions. If it does, the iodine sorption test is affected in the following two ways.

1. It is no longer possible to interpret iodine uptake on cellulose acetate solely in terms of sorption by amorphous material, as called for by the test.

2. The quantitative application of the test to cellulosic fibers may need to be reviewed, since Schwertassek [5], on whose work this aspect of the test is largely based, used secondary cellulose acetate as one of his calibration standards of completely amorphous material.

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T. G. MAJURY

Air Conditioning Unit for Fiber Research Laboratories

ANDERSON, CLAYTON & CO.
Fiber & Spinning Laboratory
Houston, Texas
March 7, 1956

To the Editor
TEXTILE RESEARCH JOURNAL

Dear Sir:

Fiber testing under carefully controlled atmospheric conditions is now common in the cotton manufacturing and merchandising industries, as well as in the rayon and synthetic fiber industries. Due to the effects of moisture on fiber strengths and elastic behavior and to the time required for the fiber to reach moisture equilibrium, it is necessary to maintain the desired atmospheric conditions continuously. This requires very rugged equipment, particularly in hot, moist climates.

Conventional air conditioning equipment is built to reduce the temperature and, simultaneously, the humidity at a fixed rate proportionate to the reduction of temperature. This fixed ration of reduction of temperature to reduction in humidity is determined by the design characteristics of the equipment. Temperature alone is under control, and as the cooling process is stopped, dehumidification is stopped also.

In such conventional equipment, there is no provision for relative humidity control. During moist weather, the cooling of the air causes condensation on the coils, and the air becomes dryer as it warms up in the room. It will, however, drift up and down in proportion to the relative humidity before cooling, and also in proportion to the running time required for cooling. Where humidity control is necessary, as it is in fiber testing laboratories, there must be an additional provision made for it in the air conditioning unit. The unit must be able to remove the moisture that is above the desired limit and, when required, add moisture when it goes below this limit. In order to control both relative humidity and temperature, it is necessary for the air conditioning system to maintain some predetermined standard condition, regardless of outside atmospheric conditions.

Air conditioning units using direct expansion for cooling and dehumidifying must be set to operate continuously in order to avoid oscillations beyond the $\pm 2°$ F. and the $\pm 2\%$ relative humidity which are desired for accurate testing. In the summer when it is hot, the cooling system runs continuously, and it is counterbalanced with a reheat of the air. The same cooling coils remove moisture from the atmosphere in order to reduce the relative humidity to an acceptable level and work against a spray system or air wash where moisture is added back to the air in the correct amount. Since it is not feasible to control the removal of the correct amount of heat and moisture by the use of direct expansion of refrigerant, it is necessary to overcool and overdehumidify, and then add back the correct amount of heat and moisture to obtain satisfactory results.

Although there are brief periods of time when neither cooling nor dehumidification is needed, the overload caused in starting the compressor motor

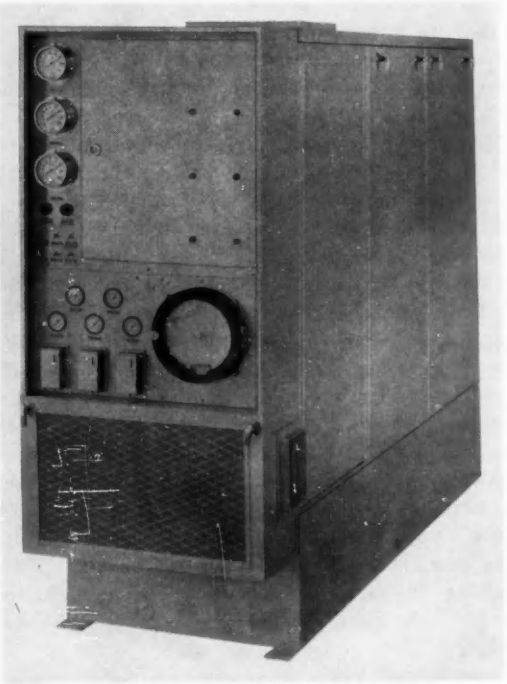

Fig. 1. Photograph of ACCO Psychronditioner showing instrument panel, fresh air intake and return air grill.

tends to wear the equipment unduly so that, as a rule, in the units designed for laboratory air conditioning setups, the machines are set to run continuously except when closed down for repair. This is expensive in operation and maintenance, including the replacement of parts.

The ACCO Laboratory has made a study of air conditioning to determine the most suitable means of maintaining standard conditions for precision fiber testing. It has been found that by using a variable temperature water spray system, a much more uniform condition can be maintained at a much lower cost, particularly in service costs in maintaining the equipment. The ACCO Psychronditioner employs such a system, blending cold, recirculated, and hot water to obtain a spray of appropriate temperature; thus the proper amount of heat and moisture is removed without overcooling or overdehumidifying. The water is cooled by direct expansion coils using one or more compressors of the correct size. The heat, like cooling, is applied to water, which is then blended with the recirculated water to obtain the correct temperature. The temperaturized water is used to condition the air, which is circulated through the laboratory. Uniform conditions are maintained by a master wet bulb controller which is used to adjust a submaster controller, which, in turn, controls the spray. The use of a humidistat, which operates on a change in relative humidity, has been avoided, since relative humidity is itself changed by variations of both temperature and moisture. The wet bulb and dry bulb thermostats thus make for finer precision control in both temperature and relative humidity.

The entire mechanism is housed in a cabinet, the size of which depends on the tonnage required. The control panel, including a recorder and the return air inlet, is on one end of the cabinet (Figure 1). This portion of the cabinet projects into the room to be conditioned. There is a fresh air inlet adjacent to the return air grill. The duct for transmitting the conditioned air into the room is on top of the cabinet.

The ACCO Psychronditioner is complete, ready to be set in place and connected to water, electricity, a drain and, when needed, hot water or steam. It does not require an air conditioning engineer and can be operated by laboratory personnel.

WALTER C. TIMMERMAN

The Preparation of Fibers from Small Quantities of Protein Solutions

WOOL TEXTILE RESEARCH LABORATORY, C.S.I.R.O.,
Biochemistry Unit
Melbourne, Australia
December 14, 1955

To The Editor,
TEXTILE RESEARCH JOURNAL

Dear Sir:

In connection with the separation of the proteins of wool into various fractions [1], it has been of interest to know whether or not a particular fraction is capable of forming a coherent fiber when extruded into a suitable medium. Forms of apparatus have been described [3], but these are not always convenient for use with quantities of protein solution of about 0.5 ml. For these amounts, a small syringe may be used, but more satisfactory results can be obtained with the apparatus described below.

There are three sections to the apparatus (see Figure 1); the protein solution reservoir *A*, capacity about 1 ml., the reservoir jacket *B*, and the precipitating column *C*. *A* is supported on a glass rod *D* passing through a rubber stopper *E*. If *D* is lubricated well with glycerol, a twisting and pushing motion will raise *A* to the position *A'*, where it comes to rest against the incurving portion of the jacket at *F*. In this position, a capillary *G* just reaches the bottom of *A*. After passing through the neck *H* of *B*, *G* continues as a thick walled capillary *I*, where a removable tip is attached by plastic tubing. Air or nitrogen under pressure (4 to 6 p.s.i.) can be ad-

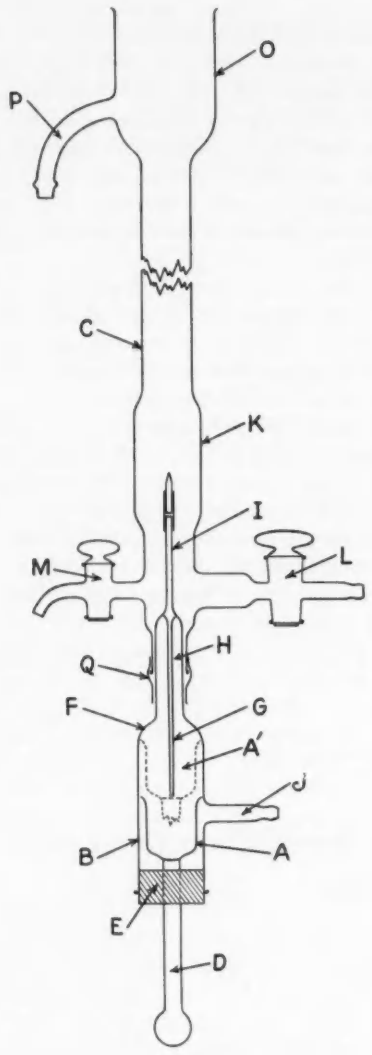

Fig. 1.

mitted to *B* by the side tube *J*. The precipitating column *C* is formed from a 22-cm. length of 10-mm. i.d. tubing, with an enlarged section at *K*, a 5-mm. bore tap at *L*, a 3-mm. drain cock at *M*, and an open top of 6 cm. of 40-mm. tubing *O* with an overflow tube *P*.

Protein solution is filtered through a fine sintered funnel directly into *A*, which is then lowered and secured into the bottom of *B* by the stopper. *B* is then inserted into the bottom of *C* where it is retained by the rubber sleeve *Q*. Air or nitrogen is now admitted through *J*, and the precipitating solution run in through *L* at a suitable rate from a 10-liter elevated container: the overflow from *P* is collected. The fine stream of bubbles issuing from *I* prevents the precipitating solution from entering *A*. Upon raising *A* to *A'*, solution is forced into the precipitating column and the fiber so formed may be collected at the top by means of tweezers and drawn off at the desired rate, preferably by means of a winding mechanism. The extrusion may be interrupted and restarted at will, simply by lowering and raising *A*. Solutions of each of the freeze dried wool extract fractions *A–F* (Gillespie and Lennox [1] were prepared by adding water (1 ml.) to the extract (0.2 g.) and then a drop of 0.1 *M* thioglycollic acid and a drop of 5 *M* KOH to bring the material completely into solution. Each solution was filtered into *A* and extruded into a solution of H_2SO_4 (270 g.) and Na_2SO_4 (600 g.) in water (1830 ml.). Fraction *B* yielded filaments which when wet were strong enough to support 2 or 3 m. of their own weight. On drying, they were of course extremely brittle. From fraction *C*, filaments were obtained which were very much weaker than those of *B*, while from the other fractions, no coherent fibers could be obtained. These results are of interest in relation to the approximate M.W. studies made by Harrap [2] on these extracts, by the surface balance method. These values were *A*, $22.9 \pm 1 \times 10^3$; *B*, $46.8 \pm 1 \times 10^3$; *C*, $37.7 \pm 1 \times 10^3$; *E*, $29.6 \pm 1 \times 10^3$; *F*, $32.5 \pm 1 \times 10^3$, suggesting that fiber formation in this series of extracts may be a function of the mean molecular weight.

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J. P. E. HUMAN

INDUSTRIAL SECTION

A New Process for Compacting Textile Materials[1]

Part I: Research and Development[2]

Walter J. Hamburger and Kenneth R. Fox

Fabric Research Laboratories, Inc., Dedham, Mass.

Introduction

The mechanisms responsible for shrinkage resulting from laundering and means for controlling it have been the subject of research by many investigators [1 through 6, 8, 11, 12]. Mechanical means for controlling laundering shrinkage of woven cotton fabrics have been commercially available for the past twenty years. However, satisfactory control of relaxation and swelling shrinkage, by mechanical means, of a wide range of fabric structures composed of either natural or synthetic fibers or both, has been achieved only recently.

In order to trace logically the steps in the development of this new process, some historical background of research in the field is necessary.

Considering all fibers and all mechanisms thought to be pertinent to the instability of textile structures resulting from wetting, drying, and agitating, the wool fiber is unique in that textile structures made from it evidence shrinkage, attributable to the fiber surface character as well as to its elastic behavior and its swelling properties. Wool fabrics shrink from felting, and in addition, from swelling recovery and its concomitant relaxation of strains.

Bogaty, Sookne, and Harris [2] sum up the requirements of felting as follows:

"Sufficient advance in the theory of the mechanism of the felting of wool has been made in recent years so that there is general agreement as to the contribution of such factors as the frictional and mechanical properties of the wool fiber. Thus, it is now recognized that in order for felting to be possible, a fiber must possess a surface scale structure, must be easily stretched and deformed, and must possess the power of recovery from deformation."

Alexander [1] comments as follows:

"The fundamental causes of felting are much more complex than was thought even a few years ago. Felting depends on fiber migration and consists essentially of fibers moving into entanglements of other fibers and the pulling together of these denser areas so as to consolidate and reduce in area the whole fabric. Wool possesses the unique surface property known as the differential friction effect (D.F.E.) of having a greater coefficient of friction in one direction (tip to root) than in the other.

"It is widely held that this property is responsible for the pulling together of the entanglements. Thus, the root end of a fiber protruding from an entanglement moves into another entanglement and because of the D.F.E. the two will be pulled together."

The shrinkage behavior of all other known fibers, both natural and synthetic, *excludes* the felting effect which occurs with wool. In this presentation the mechanisms which will be considered are swelling and swelling recovery, and relaxation of strains induced by processing.

Since swelling is such an important mechanism, some pertinent data are reproduced in Tables I and II for convenience:

Collins [3] summarizes the general mechanisms involved as follows:

"At the outset, there are two essentials that need to be emphasized since they constitute a continuous background to all aspects of the problem. The first

[1] Delivered at the 26th Annual Meeting of Textile Research Institute, Hotel Commodore, New York, March 23, 1956.

[2] Part I delivered by Walter J. Hamburger; Part II delivered by Kenneth R. Fox.

TABLE I. Swelling Properties of Textile Fibers *

Fibers	Increase in length (%)	Increase in diameter (%)
Nylon	1.2	5
Cotton	1.2	14
Wool	1.2	16
Silk	1.7	18.7
Viscose	3–5	26

* From Meredith [7] in Preston's "Fiber Science."

is that shrinkage does not occur unless water gains access to the material by one means or another. The second is that the shrinkage can then be ascribed to two causes: swelling and release of strains. The release of strains that have previously been imposed occurs when the material is wetted; the swelling that also occurs when water is absorbed produces an internal rearrangement that can result in external shortening."

Structural Factors Affecting Fabric Shrinkage

It is important to establish the trend and magnitude of effects which might be produced from alterations induced by swelling of fibers in the yarn structure, and further to consider the influences which construction variables can exert on fabric shrinkage.

Effect of Fiber Swelling on Yarn Structure

A. *Yarn cross section.* For purposes of demonstration the yarn cross section is idealized, and assumed circular and composed of circular fibers which are arranged in a rotationally symmetrical array. (Figures 1 through 3). Figure 1 represents the geometry of the yarn cross section in its normal unswollen state. Figure 2 represents the geometry of the yarn cross section after the component fibers have swollen 20% diametrically. Figure 3 represents the geometry of the yarn cross section after recovery from the swelling indicated in Figure 2.

It is to be noted that in Figures 1 and 2 the fibers are represented in a jammed state, being mutually tangent at points of contact. This mutual tangency dictates that no fiber distortion exists as a result of radial compressional forces and that the fibers were free to move outward radially as they swelled. The increase in yarn diameter as indicated in Figure 2 is a direct result of fiber swelling, with essentially the same yarn bulk density existing as it did in Figure 1, prior to swelling. Figure 3 on the other hand, shows the fibers in an unjammed state, i.e., not in mutual contact. The yarn diameter in this case is greater than that of Figure 1 but less than that of Figure 2. The yarn bulk density in this case (Figure 3) is lower than either that of Figures 1 or 2.

The fiber distribution in Figure 3 is now such that each fiber comprising the cross section can swell to the maximum (in this example, 20%) without exceeding the yarn diameter established for the swollen state and indicated in Figure 2. The geometry of cross section created in Figure 3 provides adequate voids between fibers, into and out of which the fibers may move while swelling and deswelling, permitting them to repeatedly reach the jammed state and still preserve the final swollen yarn diameter established

TABLE II. Swelling Properties of Textile Fibers (in Water) *

Fibers	Transverse swelling: Diameter	Transverse swelling: Area	Axial swelling	Vol. swelling
Cotton	20–30	40–42		42–44
Linen		47	0.1–0.2	
Jute	20–21	40		
Mercerized cotton	17	24†,46†	0.1	
Mercerized linen			5.6	
Viscose	25,35,52	50,65–67,113	3.7–4.8	74,109–127
Cuprammonium rayon	32,41,53	56–62	2–6	68,103–107
Fortisan		22		
Acetate	0.6, 9–14	6–8	0.1–0.3	
Wool	15–17	25–26		36–41
Silk	16.3–18.7	19	1.3–1.6	30–32
Nylon	1.9–2.6	1.6–3.2	2.7–6.9	8.1–11.0

* From Preston and Nimkar [10] "The Swelling of Fibers in Water."

† Various investigators have reported various values. The reader is referred to the original paper for a detailed list of references.

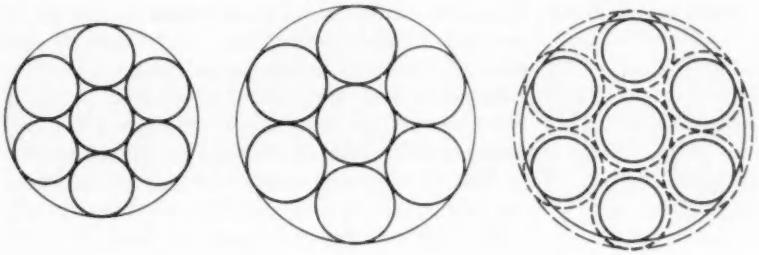


Figure 1 Figure 2 Figure 3

Figs. 1–3. Idealized yarn cross sections.

in Figure 2. The importance of this basic mechanism will be obvious as the analysis proceeds.

B. *Yarn length.* The major variables which will be considered are yarn size and yarn twist. As will be indicated by the analysis, yarn swelling produces yarn shrinkage if the yarn is twisted [9]. This will be so even if the fibers which comprise the yarn do not in themselves shrink in a direction parallel to their long axes or even if the fibers increase slightly in length when wet as cotton fibers may do.

For purposes of analysis, the yarn is considered to be made up of fibers, all of which lie at helix angles to the yarn axis, the tangent of these angles being proportional to the distance of the fiber center from the yarn axis. Thus, we may write for a helix

$$\tan \theta = 2\pi N r \tag{1}$$

where N = yarn twist in turns per inch, and θ is the helix angle for fibers distant r inches from the yarn center. This geometry is illustrated in Figure 4. The maximum helix angle occurs on the outside of the yarn and is represented by θ in Figure 4.

Consider the outside fibers in the yarn. It is clear that for a given twisted yarn length, L_o, any fiber passing through the yarn must be longer than L_o because of the spiral path the fiber travels. Since the helix angle is considered to be constant with yarn length, the fiber length, l_f may be written as

$$l_f = \frac{L_o}{\cos \theta} \tag{2}$$

In the subsequent analysis, l_f will be considered constant. That is to say, it is assumed that the fiber length is not changed during swelling even though it will be assumed that the yarn swells as a result of wetting. This assumption of constant fiber length is not unreasonable since the literature indicates axial swelling of most fibers to be of the order of 1 to 2%. Viscose and nylon are exceptions but as will be seen as this analysis proceeds, the 3 to 5% swelling of viscose can still be neglected, and the *longitudinal* swelling of nylon is not pertinent since its *diametric* swelling is too low to cause fabric shrinkages of any great moment.

Let R be the original yarn radius in inches. The degree of swelling is defined as β where

$$\beta = \frac{(R_s)^2}{(R_o)^2} \tag{3}$$

Thus, β represents the ratio of swollen to original cross-sectional area of the yarn.

When the yarn swells, yarn shrinkage will occur. The total number of turns of twist may be considered unchanged, but since the yarn length is less, the turns per inch in the swollen state will be greater than that in the original yarn. Thus

$$N_o L_o = N_s L_s \tag{4}$$

and

$$N_s = N_o \frac{L_o}{L_s} \tag{5}$$

where the subscript o and s refer to original and swollen state respectively.

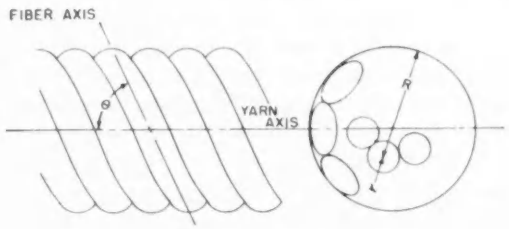


Fig. 4. Idealized yarn geometry.

Since the fiber length is considered as constant, we may write, from Equation 2

$$l_f = \frac{L_o}{\cos \theta_o} = \frac{L_s}{\cos \theta_s} \tag{6}$$

Thus

$$\frac{L_o}{L_s} = \frac{\cos \theta_o}{\cos \theta_s} = \sqrt{\frac{1 + \tan^2 \theta_s}{1 + \tan^2 \theta_o}} \tag{7}$$

Since

$$\tan \theta = 2\pi NR \tag{8}$$

Equation 7 may be written as

$$\frac{L_o}{L_s} = \sqrt{\frac{1 + 4\pi^2 N_s^2 R_s^2}{1 + 4\pi^2 N_o^2 R_o^2}} \tag{9}$$

Substituting Equations 3 and 5 in 9 after squaring both sides of Equation 9, there results

$$\frac{L_o^2}{L_s^2} = \frac{1 + 4\pi^2 N_o^2 \frac{L_o^2}{L_s^2} \beta R_o^2}{1 + 4\pi^2 N_o^2 R_o^2} \tag{10}$$

After simplification, Equation 10 reduces to Equation 11.

$$\frac{L_o}{L_s} = \sqrt{\frac{1}{1 - (\beta - 1) \tan^2 \theta_o}} \tag{11}$$

Now, the per cent shrinkage is defined as

$$S = 100 \left[1 - \frac{L_o}{L_s} \right] \tag{12}$$

Therefore

$$S = 100[1 - \sqrt{1 - (\beta - 1) \tan^2 \theta_o}] \tag{13}$$

Equation 13 defines the yarn shrinkage in terms of two variables, namely, yarn helix angle θ_o and yarn swelling β. It is found from Equation 13 that increases in either of the two variables produce increases in the yarn shrinkage. It should be noted that Equation 13 presumes that the outer fibers can produce yarn shrinkage independent of any restrictions by any of the remaining fibers in the yarns. Actually, the case of no restriction can only occur if the axial compressional resistance of the internal fibers is negligible, since only then would the inner fibers offer no resistance. This is probably not the case in actual yarns, and so Equation 13 which presents the theoretical interdependency of swelling and twist gives too high a value for the yarn shrinkage. The deviation of theory from practice increases as the yarn twist increases, since higher yarn twists have the effect of increasing compressional resistance.

In addition to the previous limitation involving fiber motion, the assumption of a constant β demands consideration. It is clear that β, the degree of yarn swelling, is functional with the density of fiber packing. Fiber packing is related to twist. Thus changes in θ_o produce changes in β, and this must be clearly recognized in the application of the theoretical analysis. This emphasizes the need for experimental research to define the degree to which yarn structure affects yarn swelling. Also, from the discussion above, increases in yarn twist tend to decrease the ability of the yarn to conform to the length change demanded by the outer fibers. Finally, the method of drying a yarn can materially alter the degree of yarn shrinkage due to swelling. Thus, slight tensions on the yarn while drying takes place could, when combined with the restricting influences of the inner fibers, eliminate completely the shrinkage due to swelling.

It is apparent then that Equation 13 is only a guide to the trend of changes in shrinkage with changes in yarn structure.

As an index of the magnitude of yarn shrinkage resulting from swelling, Equation 13 will be solved for the case of a yarn with a knitting twist multiplier of about 3.5 T.M. Such a twist results in a surface helix angle θ of 24.3°. Also, it will be assumed that $\beta = 1.40$.

$$\tan 24.3° = 0.45$$

$$S = 100[1 - \sqrt{1 - (0.40 \times 0.20)}]$$

$$S = 100[1 - 0.96] = 4\%$$

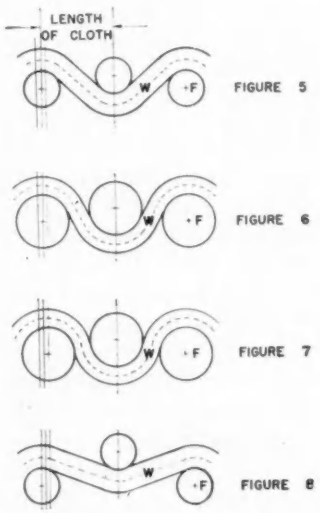
The actual yarn shrinkage would probably be less than 4% because of the reasons already enumerated. Thus, it is apparent that the large shrinkages which occur in fabric structures can certainly not be accounted for by the relatively low shrinkages which could theoretically exist as a result of yarn contraction resulting from fiber swelling and its attendant yarn diameter increase. Collins [3] confirms these facts when he states, "on all accounts, therefore, the shrinkage of cotton yarns of moderate twist is likely to be small, and it may be observed that in many routine measurements of shrinkage of cotton fabrics that have been carried out at the Shirley Institute, the shrinkage of the yarn itself has rarely exceeded

2%, or at the most 3%, and has usually been from 1 to 2%."

C. *Yarn take-up due to crimp changes.* It is immediately obvious that the large shrinkages which can occur in fabrics made from hydrophilic fibers must be attributable to certain construction variables which are developed by the fabric structure itself.

A consideration of a representation of the elements of fabric structure can be helpful in developing the mechanism involved.

Figure 5 is a diagrammatic representation of a section of fabric showing warp in longitudinal section and filling in cross section. The warp yarn is shown finer than the filling yarn, and the warp bends around the filling more than the filling bends around the warp. The difference between the length of the warp yarn and the length along the fabric, expressed in per cent, is the crimp of the warp yarn. When the fabric is wet and the fibers and yarns swollen, as shown in Figure 6, a greater length of warp yarn will be required to adjust to the increased diameter of the filling if the filling yarns remain the same distance apart. This adjustment in length can occur by stretching of the warp yarn, but the force necessary to stretch the yarn is much greater than that necessary to move the filling yarns closer together if the fabric is not restrained, and as indicated in Figure 7, this occurs with a further increase in warp crimp which causes a shrinkage of the fabric warpwise. Decrease in spacing of filling yarns can continue until warpwise jamming of warp and filling yarns take place. This jamming limits the extent of shrinkage which can take place in this direction. A like limiting condition, of course, exists when fillingwise jamming takes place.



Figs. 5–8. Yarn take-up due to crimp changes. Diagrammatic representation of a section of fabric showing warp in longitudinal section and filling in cross section.

Eliminating the crimp from the warp would, of course, eliminate shrinkage as well as the tendency to stretch the warp as a result of diameter changes. However, the crimp eliminated from the warp would be exchanged to the filling, thereby increasing the crimp fillingwise and causing a corresponding increase in fillingwise shrinkage. The geometry of woven cloth structure requires that as a result of swelling, the fabric must contract warpwise or fillingwise or both, the final state depending upon fabric construction variables and previous processing history of the fabric and its component parts. Shrinkages caused by crimp increases can be much greater than those possible from the yarn shrinkages induced by twist or by relaxation.

The other mechanism which requires attention is that which causes shrinkage as the result of the release of strains which have been previously imposed during processing. In finishing, fabrics may be subjected to large tensile forces while wet and may be held in the restrained state of strain during drying. The extension thus locked in may be quite permanent. The resultant structure is represented in Figure 8. This is not a normally stable structure since at thread intersections the finer thread will be bent more easily than will the coarser thread. Also fine warps are usually spaced closer together for proper cover, and this closer spacing develops less mechanical advantage for bending the coarser filling.

When such a structure is wet out the fabric will achieve a more stable state of crimp balance by means of relaxing the strains locked in as a result of finishing under tension. The crimp interchange so induced can account for shrinkages of the order of 10% or more in cotton fabrics [3].

Collins [3] summarizes the factors affecting cotton cloth shrinkage:

"The largest amount of the shrinkage is that which is represented by increase of crimp, yarn shrinkage takes second place, being generally much less than increase of crimp, whilst fiber shrinkage is usually negligible."

It should be obvious, however, that all these mech-

anisms of shrinkage are based upon the ability of the *fiber* to swell *diametrically*.

Development of the Compactor

From the foregoing discussion of the mechanisms responsible for laundering shrinkage of fabrics, it appears that for applications where hydrophilic fibers are employed, control of shrinkage can be achieved by two basic procedures, namely:

1. Reduce shrinkage by inhibition of fiber swelling.
2. Induce shrinkage as part of the finishing procedure so that no significant increase will occur on subsequent washing.

Inhibition of fiber swelling eliminates or substantially reduces the development of fabric contraction resulting from crimp increases. It does not, however, eliminate shrinkage resulting from relaxation of strains. Inducing shrinkage as part of the finishing procedure, so that no significant increase will occur upon subsequent washing, contemplates the development of crimp increases as a fabric-contracting mechanism and also contemplates relaxation of strains.

The increase of the diameter of the fibers upon wetting, which causes increase in yarn diameter, does not occur instantaneously upon wetting, nor is it necessarily complete in one wetting and drying cycle. Actually, while in the first wash relatively large diameter increases occur, locked-in strains, resulting from previous processing history, require spatial readjustment of the gross structure for their elimination. The degree to which these strains may be relaxed is governed by the extent to which freedom of relative motion of the individual structural elements is inhibited by mechanical or elastic restraint or both. Agitation of the structure is helpful in relieving such conditions of strain, and repeated subsequent washing and drying is an effective means of additional strain dissipation.

Collins states in this regard:

"These strains can be pictured as places in the yarn where 'sticking' has occurred; when the yarn dries, free spaces develop, and this allows of accommodation between fibers with a less 'strained' and more shrunk structure when the cloth is wet out again. Agitation during the washing treatment helps to overcome these local strains and therefore promotes shrinkage."

It is well known that time, temperature, moisture content, and stress or strain intensity are important variables in the behavior of viscoelastic materials. A high stress applied for a short time can be as effective as a low stress applied for a long time. The stresses necessary for *permanently* increasing the diameter of a yarn by axial compression, to the extent achieved by swelling, are relatively high, and since yarn structures are extremely flexible it is very difficult to create an absolutely symmetrical axial compressional force over any great laterally unsupported length of yarn. As a result, the yarn will buckle or bend, before the required intensity of axial compressional stress is reached, unless the stressed laterally unsupported length is reduced to the point where buckling does not occur. To accomplish this would in effect make it possible to "push on a rope" with sufficient axial compressional force to create a permanent deformation by opening up the rope structure diametrically. This axial compression will also serve forcibly to overcome the mechanical and elastic restraints referred to above in reference to locked-in strains, and also to create the "voids" in the yarn structure to which Collins referred as noted previously.

It should now be evident that if such mechanisms could be developed, all the requirements essential for preshrinkage would be provided, namely, yarn diameter increase and relaxation of residual strains. The compacting machine is a mechanical device capable of developing such mechanisms, and its operating characteristics will now be described.

The compacting machine, as originally conceived by Richard R. Walton, Boston, Mass., consists primarily of two rolls mounted on parallel axes and slightly spaced apart, and a horizontal plate which is in contact with the upper roll surface along a line vertically slightly above the point of true mutual tangency of the upper and lower rolls, and horizontally at a point slightly displaced from the vertical meridian common to both rolls.

The upper roll may be covered with a resilient compressible material, the lower roll may be constructed of a relatively noncompressible material with a rough surface such as sprayed stainless steel, or of a resilient compressible material softer than and exhibiting a higher coefficient of friction than that of the upper roll. The peripheral velocity of the upper roll is greater than that of the lower roll. This velocity ratio is variable to accommodate various types of fabrics. (However, the upper roll velocity must always exceed that of the lower roll.)

Introduction of a fabric of greater thickness than the spacing between the rolls causes a deformation of the upper roll surface (and also of the lower roll surface when the lower roll is constructed with a resilient compressible material). This deformation creates an extended arcuate nip between the rolls while the fabric is present, the length of which is a function of fabric thickness and fabric and roll compressional properties.

The fabric is introduced at the nip formed by the edge of the plate and the upper roll (N_P on diagram, Figure 9), and feeds, at the approximate speed of the upper roll, into the nip formed by the slightly spaced apart upper and lower rolls, causing an arcuate extension of the nip which otherwise would be located at the point of true mutual tangency if no distortion occurred as a result of fabric thickness. The fabric, in this arcuate extended nip, is reduced in velocity due to the reduced speed of the lower roll. The velocity gradient thus produced in the fabric, while it advances from the plate nip N_P to the entrance point E of the arcuate extended roll nip N_R, induces compressional strains in the extremely short length of fabric N_PE. This length of fabric acts as a columnar sheet fixed at both ends (by nips N_P and N_R) but laterally *unsupported* and free to expand in thickness. The position of the edge of the horizontal plate is adjusted to create a column length such that buckling of the laterally unsupported columnar sheet is reduced to an absolute minimum. Under these conditions the forces exerted by the restrained forward motion of the fabric from N_P to E develop high compressional strains in the direction of travel of the fabric rather than bending strains which would result if the columnar sheet were of sufficient length to buckle.

These compressional strains result in a repositioning and opening up of the entire fabric structure, which cause a decrease in length of the fabric in the direction of travel and a growth in its thickness. The decrease in fabric length will, of course, result in increased weight per square yard, thereby increasing the linear density of the fabric. However, since the thickness is materially increased as a result of the repositioning and opening up of the elements of the fabric structure, the bulk density of the entire system may be reduced. The extent to which these two density considerations may vary is a function of fabric structure and extent of compacting.

The significance of these alterations in fabric structure and the industrial application of the compacting machine as a new tool for textile finishing will be comprehensively presented in Part II of this paper.

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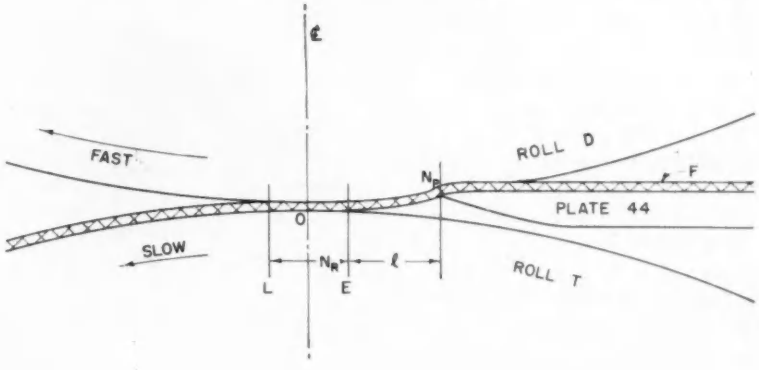

Fig. 9. Diagrammatic representation of a fabric sample being compacted.

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Part II: Industrial Applications

Introduction

In Part I of this paper, theoretical consideration has been given to the mechanism of shrinkage in a textile fabric and what must be done to render a fabric stable to subsequent washing. A mechanical process has been described which has been found useful in compacting fabrics of a wide range of weights and fiber contents.

It is the purpose of this part of the paper to show how the compacting machine was developed to the point of actual plant installations, to describe how these machines can be used in conjunction with other standard textile processing equipment, to present some of the data that has been accumulatd on a wide range of fabrics, and to point out the universality of the machine by citing a number of special applications.

Machine Development

The first laboratory machine invented and built by Richard R. Walton of Boston, Mass., is shown at the top of Figure 1. This unit is 12 in. wide, simple in construction, effective in its action, and is still used for demonstration purposes. However, it was felt that before a machine to handle full-width fabric should be constructed, a careful study of the various factors involved in the process should be conducted for design purposes. Accordingly, a 24-in. wide machine was built, and a photograph of it is also shown in Figure 1. This unit includes a steam box on the entering side and permits among other variables, an investigation of various methods of fabric conditioning. A slightly modified form of blade was used, roll sizes were increased in diameter, and top-roll moistening attachments were added, but the basic machine remained substantially the same as the 12-in. unit. This second unit is the one on which our laboratory samples are run and the small size permits an appraisal of results without consuming much fabric.

Based on encouraging results from this second laboratory machine, it was decided to go ahead with a full-width machine to handle 60- to 62-in. goods. Riggs & Lombard, Inc., Lowell, Mass., were contacted to help engineer and develop this machine,

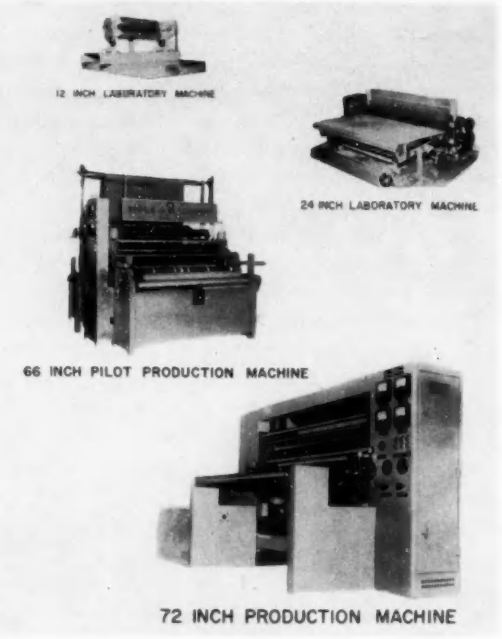


Fig. 1. The production machine and the various stages of development.

and the results are shown in Figure 1, as the pilot production machine. This unit is installed in our laboratories and has been in operation on full-width sample lots for over a year. Again, the basic mechanism is similar to the first 12-in. unit, but several accessories have been added, such as unwind rolls, a wet-out tank and squeeze unit, spreaders, a steamer, and a conveyor to take the fabric away from the machine. A compensating roll was built in to take care of roll deflections, and a flock brush was inserted to keep the bottom compacting roll free of fiber accumulation.

The next step taken was the design and construction of a production unit with a specific plant installation in mind. At the bottom of Figure 1 is a photograph of a 72-in. wide production machine which was delivered last fall. A similar machine was delivered to another mill at approximately the same time. Not only is the over-all appearance of the machine greatly improved, but motions were simplified and drives improved. Inasmuch as both of these machines were designed to run in line, the entering and delivering ends were changed from the former machine. Floor space requirement is relatively small with the 72-in. machine taking approximately 13 ft. in width and 5 ft. in depth. Further details on the machine can be obtained from Riggs & Lombard, Inc.

Machine Installations

There are many ways to install the compacting machine. The actual setup depends upon many factors such as the type of fabric to be run, the amount of moisture normally in the goods, type of finish, etc., as well as the kind of drying equipment available. The fabric has sufficient moisture to soften and/or lubricate its elements, and the use of heat in the form of steam is most desirable; hence, a steamer is specified as standard equipment.

Figure 2 is a schematic diagram and shows the compacting machine placed between a pad and a tenter drier. This is a rather flexible arrangement and permits several possibilities. If dry goods requiring no finish are to be compacted, the material would be wet out with water on the pad, steamed, compacted, and sent through the drier—all as one operation. Of course, if the goods are brought to the machine in the wet state, then no wetting out on the pad would be necessary. A similar situation would exist in the case of resin-cured goods. If dry, then wet out is necessary before steaming and compacting, but if the goods are brought to the machine wet, for example, from scouring after cure, then only steaming is required before compacting. If it is desirable to apply finish to the fabric for the sake of hand, wrinkle resistance, water repellency, etc., this may be done on the pad prior to compacting. The arrangement of equipment shown in Figure 2 is recommended for cotton, synthetic blends, and in general, fabrics where wool is not the dominating fiber.

Figure 3 is the recommended arrangement for wool and wool blends. It is not necessary to have wet out cloth for compacting this type of fabric; hence, no pad is shown. Steaming, on the other hand, will plasticize the fabric elements to release strains, and to permit optimum compacting. If, because of finishing routines it is more practical to compact wet goods, this can be done by feeding the cloth in the wet state to the steamer, but heat is still recommended to do a thorough job of compacting. Overfed pin drying is recommended, but any system of drying that keeps tensions low would probably be satisfactory.

The compacting machine does not necessarily have to be set in line with other equipment. This is generally desirable from a cost point of view, but compacting can be done as a separate operation as well. Suitable let-off and batching mechanisms would be employed. The fabric should then be dried. It is recommended practice to do compacting as close to the final operation as possible to avoid pull-out from further processing, and wet processing after compacting must be avoided. It has been suggested that the compacting machine might be hooked up in tandem with a decating unit, but this has not been

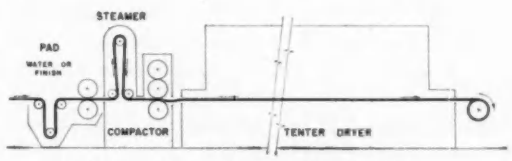


Fig. 2. Compacting machine installation.

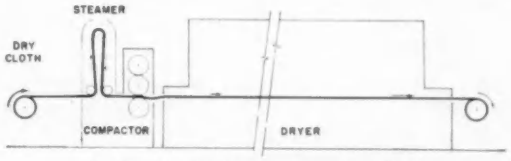


Fig. 3. Compacting machine installation.

attempted. However, dry compacted goods have been decated or calendered successfully without losing compaction.

Compacting Machine Results

As pointed out in Part I of this paper, one of the unusual features of this process is that, along with a lengthwise compacting of the material and an adjustment of filling tensions, there is freedom for the fabric to grow in thickness. This action has produced some rather unique effects, and as a consequence, a mere tabulation of shrinkage data tells only a portion of the results. It is only by seeing the fabric and judging the hand and surface that a full understanding of the process capabilities can be appreciated. Consequently, in addition to the presentation of shrinkage data, an attempt will be made later in the paper to point out these transformations, and samples will be available for examination.

Several hundred different fabrics have been run through the compacting machine. These have varied in weight from marquisettes and sheers to heavy fleeces and carpeting. Not all fabrics have responded equally successfully so it is generally known where limitations of the process exist. However, there has been a wide range of fabrics that have shown very interesting results. The following tables attempt to present a broad picture of these results.

Table I shows some of the results that have been obtained on all cotton fabrics. Actually, this is the field in which we have done the least work as there appear to be fewer incentives for the acceptance of a new mechanical preshrinking machine in a field where equipment is already in place. Nevertheless, there does seem to be a great deal of interest in a low cost machine which, in addition to stabilizing, emphasizes surface texture and produces cover in contrast to the flat, smooth, or calendered surface generally produced on existing equipment. It was with this thought in mind that certain samples were processed.

TABLE I. Percent Washing Shrinkage of Cotton Fabrics *

	Control		Compacted	
Type	Warp	Filling	Warp	Filling
8-Oz. twill	−4.5†	−1.5	−0.8	+0.2†
Carded broadcloth	−4.5	−3.2	+0.1	−1.5
Figured drapery	−7.5	−4.5	−0.5	+2.5
Oxford shirting	−4.0	+2.4	+0.9	0.0
Nainsook (with resin)	−1.3	−1.8	+0.2	−0.3
Poplin (with resin)	−2.3	−3.1	+0.3	0.0
Flat toweling	−5.3	−7.2	+1.2	+1.0
Muslin	−5.8	−1.5	+1.0	−1.2

* Bendix 160° F. wash, flat bed press.
† − Signifies shrinkage. + Signifies growth.

Reference to the table will show the improvement in washing shrinkage from the control to the compacted fabric. Under the method of test some of the fabrics show modest growths, but under a more severe washing test, this tendency is lost or even reversed when tumble drying is employed. Several of the fabrics which show low-control shrinkages have been resin-treated before compacting for ease-of-care properties. Progressive shrinkage on repeated washings will vary with the fabric and finish, but the range achieved is comparable to the results obtained by other compressive shrinking machines, namely, up to 1 or 2%.

Synthetic Blends

The tremendous amount of activity in the shrinkproofing of synthetic blended fabrics is well known. By and large this activity has been confined to the use of chemicals, such as resins and fiber modifying agents, which inhibit the swelling of fibers and yarns and thus reduce shrinkage. Such processes have certain limitations both as to control in processing and dependability of results. Also side issues such as chlorine retention, odor, deleterious effect on tear strength, tensile strength loss, needle cutting during sewing, variation in hand and shade, adverse effect on color fastness—all of these make such processing procedures subject to improvements. Even more pertinent, however, is the fact that residual shrinkages frequently cannot be reduced to a level that is necessary to meet some end uses. This is particularly true in the wash and wear field where ironing is not used to restore dimensions previously taken care of in a damp pressing operation.

The use of the compacting machine in the synthetic blend field opens up some interesting opportunities. It is possible, for example, to compact an untreated all-viscose fabric and achieve low residual shrinkage and good stabilization on repeated washings. However, to do this, full working loss in both warp and filling must be taken, and the goods must be very carefully handled in the wet state to avoid pull-out. Such a fabric will have a high degree of stretch, a very soft hand, poor wrinkle resistance and, except

TABLE II. Percent Washing Shrinkage of Synthetic Blend Fabrics *

Type	Blend	Control		Compacted	
		Warp	Filling	Warp	Filling
Flannel suiting	50% Viscose 50% Acetate	−2.6†	−5.0	+0.9†	−1.4
Tropical suiting	50% Viscose 50% Acetate	−4.0	−4.5	−0.5	−0.8
Check suiting	25% Dynel 25% Orlon 25% Acetate 25% Viscose	−2.0	−3.9	+0.7	+0.7
Gabardine suiting	10% Nylon 85% Viscose 5% Dacron	−4.0	−1.6	+1.0	0.0
Viscose linen	100% Viscose	−4.8	−5.9	+0.9	+0.5
Twill suiting	35% Viscose 65% Dacron	−1.9	−0.6	+0.2	+0.2
Work twill	90% Orlon 10% Viscose	−2.3	−0.5	−0.3	−0.7

* Bendix 160° F. wash, tumble dry.
† − Signifies shrinkage. + Signifies growth.

for certain end uses, very limited utility. But by combining the use of chemicals and the compacting process, neither process is being used to do the job alone and hence less compacting is necessary and the amount of chemical finish can also be reduced. The resultant fabric has good stabilization, good hand and wrinkle resistance, improved physical properties relative to a full chemical finish, and most important, an excellent cover and fullness of structure. Reediness, filling repeat patterns, cracks, etc., are greatly improved, if not eliminated.

The compacting machine has also shown fine opportunities in reducing the residual shrinkage in full resin-cured synthetic blends. Such a series of fabrics is shown in Table II. It will be noted that all of these fabrics have been tested at a 160° F. wash and tumble dry.

Figure 4 is a chart showing the amount of pro-

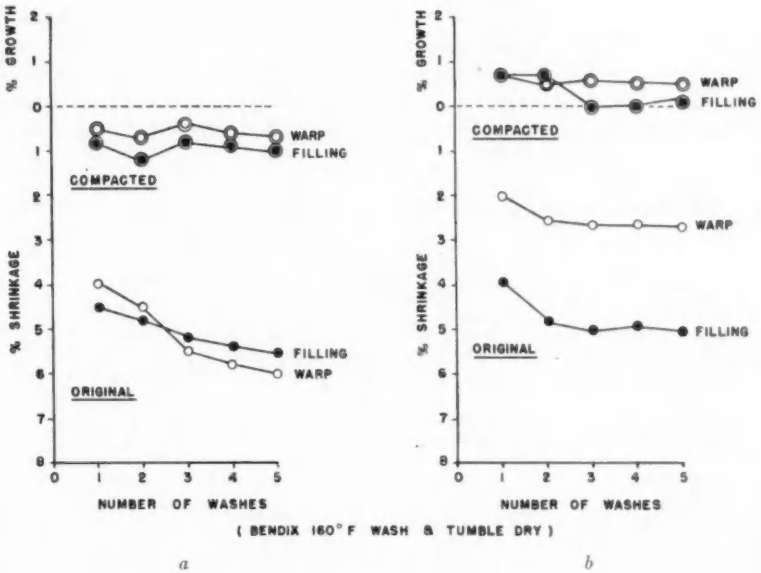


Fig. 4. Progressive shrinkages of two suiting materials; *a*, Tropical suiting; *b*, Check suiting.

gressive shrinkage on two typical synthetic blend fabrics for five washes and tumble dryings. In general, progressive shrinkage in this type of fabric can be controlled where the resin has been properly applied and does not significantly wash out on repeated washing or where the resin is not being called on to control shrinkage but only to build up hand and wrinkle resistance. Typical of this latter type of fabric are blends where the percentage of hydrophobic fibers is great enough to effectively reduce swelling shrinkage and the compacting machine eliminates shrinkage resulting from tensions in processing.

Wool and Wool Blends

The problems of shrinkage control in wool and wool blends are well known and constitute one of the mill's greatest concerns. If, on the other hand, the fabric is a washable item, felting shrinkage must be controlled as well as relaxation shrinkage. The compacting machine alone is not able to control fulling shrinkage, but in combination with suitable chemical finishes and/or significant percentages of hydrophobic or nonfelting fiber, full washable fabrics can be achieved. Table III shows some of the results achieved on wool and wool-blend fabrics tested for relaxation shrinkage. There have been many samples submitted where fulling shrinkage was well controlled, but the relaxation shrinkage was very high. The compacting machine was most effective in reducing these shrinkages.

Miscellaneous Fabrics

In the course of evaluating the capabilities of the compacting machine, many different miscellaneous fabrics have been processed in limited yardage. These fabrics generally were of the type where no known mechanical process had been successful in removing shrinkage, or where shrinkage had been removed but the appearance of the fabric had suffered from flattening. Table IV shows some of the results and samples available for inspection.

Yarns

Some very interesting preliminary work has been done in compacting yarns. It was found that yarns could be made bulkier, shrinkage could be reduced, and that, under proper conditions, stretchiness could be built into the structure. Samples are available for inspection. Riggs & Lombard, Inc., are currently building an experimental compacting machine designed for processing 50 ends.

General Considerations

Up to this point, emphasis on the results from the compacting machine has been in the field of shrinkage reduction. Yet, it is believed that this is only one, and perhaps even minor consideration, in the total picture. Fabric processing equipment almost without exception involves tensions, and thus stretch is introduced. Many attempts have been made, some with very good success, to reduce tension, and in a few cases, tensionless conveying has been achieved. Examples are overfeed mechanisms on tenter frames, short-loop driers, and apron or conveyor driers. Yet all of these depend for their success on the intrinsic tendency of the fabric to recover dimension when tensionless. Continuous washers, J boxes, and other shrink-inducing equip-

TABLE III. Percent Relaxation Shrinkage of Wool and Wool Blends *

Type	Blend	Control		Compacted	
		Warp	Filling	Warp	Filling
Fleece coating	100% Wool	−6.6†	−6.8	−2.0	−2.0
Tweed suiting	100% Wool	−10.7	−2.0	−2.0	−1.0
Flannel suiting	100% Wool	−6.6	−4.9	−1.5	−1.0
Worsted suiting	100% Wool	−5.9	−4.0	−0.6	−0.6
Gabardine suiting	50% Wool 50% Dacron	−3.0	−1.6	0.0	0.0
Twill suiting	60% Wool 40% Viscose	−6.2	−3.5	−0.7	−0.7
Women's suiting	50% Wool 50% Orlon	−4.9	−4.2	−0.7	0.0

* Shrinkage CCC-T-191b.
† − Signifies shrinkage. + Signifies growth.

ment have been used to help overcome pull-out from tension. Effort is also being made to induce greater restoration of dimension by agitating the fabric while drying.

It is felt the compacting machine permits an entirely new and different approach to the problem. As pointed out in Part I of this paper, very high and localized compressive forces within the plane of the fabric and in the direction of travel are built up so that in effect a "negative tension" is created. Here is a means of positively and controllably "pushing on a rope" and doing something other than just buckling it. Dependence for dimension change does not rest on the recovering power of the fabric alone, but the structure is forced back even beyond its preferred, comfortable position, and the fabric actually "grows" as it emerges from the compacting rolls. It follows, then, that the amount of compacting that can be accomplished is related but not necessarily equal to the amount of potential recoverability in the fabric. What, on the surface, may seem to be a limitation of the process actually turns out to be a most important practical consideration.

It is known and recognized that textile fabrics vary not only from piece to piece and lot to lot but also across and along a piece. A process that would significantly reduce the variation should be helpful. On several trial runs where such an experiment was designed, this leveling action was accomplished. Strictly by accident, it was noted in a trial piece that a lengthwise band in the fabric was compacting a greater amount. Upon checking the cloth entering the machine, it was determined that there was a band of tight ends and these were being leveled out by the process. Even more interesting are the various experiments where several fabrics different in weight, fiber blend, weave, finish and possessing, with as much as 2 or even 3 to 1 variation in shrinkage, were processed at the same time, with the same machine settings and speeds. These compacted fabrics exhibit substantially the same residual shrinkage when finished up and tested.

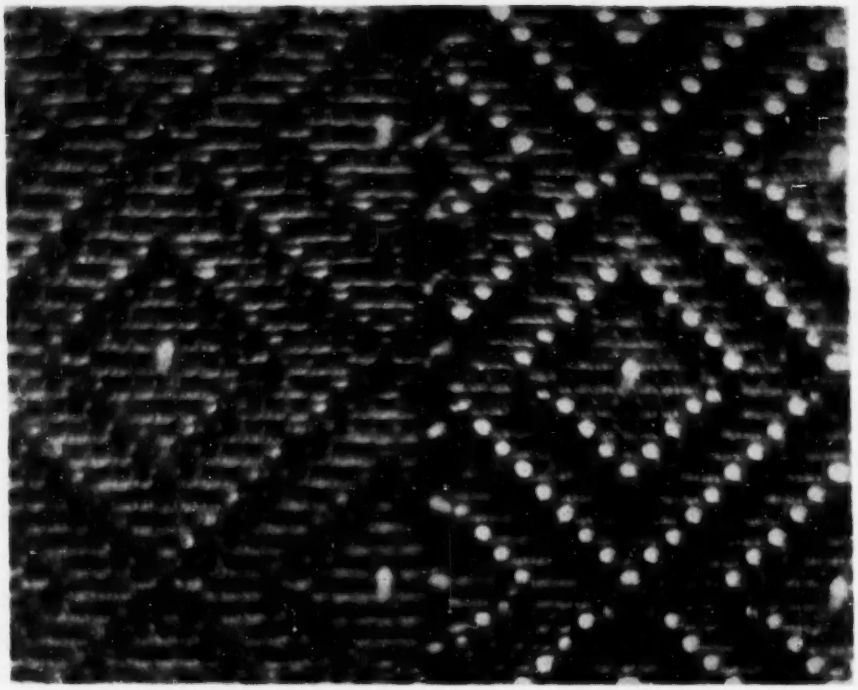
The concept of utilizing "negative tension" has proved useful in other ways as well. Take, for example, a fabric composed of 50% wool and 50% of a nonfelting fiber. Normal fulling procedures have produced a certain closing up of the fabric, but a denser structure with more cover is desired. By use of the compacting machine it has been demonstrated that a denser fabric can be obtained. Lightweight tropical worsteds that are too light-permeable can be made more opaque. 14-oz. woolens have been compacted into 16-oz. fabrics, and cloths which lack a few picks can be brought up to specification. Worsted fabrics which require a light fulling to close up the structure and impart a slight cover have been processed on the compactor full width, and the required densification achieved. Of particular interest to the synthetic fabric mills is a sample of sportcoating material made entirely of nonfelting fibers which become quite "wool-like" in appearance and hand after compacting. It is felt the surface has hardly been scratched in developing the principle of compacting textiles to simulate fulling and achieve light fulling mill effects. This subject is even more stimulating when it is realized that full-width, continuous processing may be possible.

In describing the mechanism of the compacting

TABLE IV. Percent Shrinkage of Miscellaneous Fabrics

		Control		Compacted	
Type	Test	Warp	Filling	Warp	Filling
Cotton tape	160° Wash tumble dry	−8.4*	−4.3	−0.2	−0.6
Axminster carpet	Shampoo	−9.6	−2.5	+0.6*	−2.0
Viscose bedspread	160° Wash tumble dry	−21.3	−11.5	−0.1	+0.2
Corduroy	160° Wash tumble dry	−4.1	−3.3	−0.6	−1.5
Synthetic blanket	Relaxation shrinkage	−8.7	−3.4	−2.0	−2.0
Cotton bedspread	160° Wash tumble dry	−13.8	−2.8	+0.4	−3.0
Figured upholstery	160° Wash flat bed press	−4.9	−1.6	−0.3	−2.0

* − Signifies shrinkage. + Signifies growth.



a *b*

Fig. 5. Automotive upholstery fabric; *a*, Before compaction; *b*, After compaction.

machine in Part I of this paper, it was stressed that one of the major features of the machine is that while the fabric is being compacted it is free to increase in thickness. Basically, this is the reason why pile fabrics and lofty fabrics, such as blankets, can be processed without flattening. Because of increases in thickness, it is generally found that compacted fabrics have a softer, rounder hand, and improved draping qualities. But more important is the change in surface appearance. By compacting lengthwise, warp crimp is increased, and by permitting the amplitude of the crimp to increase, warp cover is greatly improved. In the exhibited fabrics there are examples of fabrics wherein a colored warp and natural filling form the ground in Jacquard patterns. Whereas the filling is prominent in the control fabrics, the compacted fabrics have very little filling showing, and as a consequence the ground is more nearly a solid color. In other words, the flush of the fabric has been altered, and in some instances, completely reversed. Where the warp yarn forms a pattern, the figures are much more prominent, giving what one mill characterized as a "3-D" look. Figure 5 shows the surface appearance of a latex-backed automotive upholstery fabric before and after processing on the compacting machine. It is rather obvious that much more depth of weave has been added by the process. Another fabric which was designed to produce a crepe essentially lost this appearance in finishing, but was entirely restored by compacting. Fancy yarn fabrics using nubs, slubs, thick and thin yarns, and the like have had the surface interest further accentuated by compacting. Here again, the opportunities to create new and unusual effects by compacting are certainly evident.

In summary, an attempt has been made to present the development of a new method for processing textiles, to indicate the manner in which the compacting machine may be used in industrial applications, to indicate some of the results that have been achieved, and to point out further possibilities that are available for exploitation. We feel a new finishing tool has been created and are confident that the compacting machine has utility in making better and more useful textiles.

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Limitations of the Indirect Untwist-Twist and Direct-Counting Methods for Determining Twist in Carded Cotton Single Yarns

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THE determination of twist in yarns is an important consideration since it is related to strength and other quality factors in yarns and fabrics related to end-use requirements. The indirect untwist-twist method for determining the number of turns per inch in cotton single yarns has received considerable acceptance both in this country and abroad because it is simple and rapidly executed, gives fairly reproducible results, and avoids much of the tedium of direct counting. At present, it is the only method given for single yarns in ASTM D 180-52T for "Cotton Yarns" [1*c*] and in Federal Specification CCC-T-191b, "Textile Test Methods" [5]; but, in contrast, it is not mentioned in the British Standard for twist determination [12] and is specifically excluded in the ISO proposal [8].

The untwist-twist method has not been fully acceptable because its results are not always in satisfactory agreement with the values expected from machine settings or obtained by actual count. Moreover, it gives little information on the short-term variation in twist along the yarn, for only the average number of turns per inch in a 10-in. length is obtained. Consequently, the method of counting the actual number of turns in a known length of yarn has generally been considered the only reliable method [7, 9].

Because of the limitations of the untwist-twist method and the need in the textile industry of a method for accurately determining twist in cotton yarns, Subcommittee A-1, Section 2, Cotton Yarns, of Committee D-13 of the American Society for Testing Materials set up a Task Group in October 1952 to study the problems involved in determining twist in single yarns. As a contribution to this work, some experiments were made to determine the effect of tension in the untwist-twist test when applied to carded cotton single yarns, to observe the distribution of twist in a yarn when it is subjected to this test, and to compare twist values obtained by it and by actual count.

[1] One of the laboratories of the Southern Utilization Research Branch, Agricultural Research Service, U. S. Department of Agriculture.

Effect of Tension in the Untwist-Twist Test

Nine yarns were tested. They were of the mock-grandrelle type so that the twist spirals could be seen readily and counted. They were prepared by spinning together from a double creel a dark- and a light-blue roving made from dyed raw stock. The twist values were selected so that sets of yarns with different yarn numbers but approximately the same number of turns per inch would be obtained and any indications of straight-line relationships would be observed. The yarns selected were 15's, 30's, and 45's, each with twist multipliers of approximately

TABLE I. Yarn Properties

Yarn number	Property	Twist multiplier 3.00	4.00	5.00
15's	Yarn number*	15.1	15.0	15.1
	Twist, machine, t.p.i.†	11.6	15.4	19.3
	Tension to straighten yarn, g.‡	6.0	7.1	5.1
30's	Yarn number	30.0	29.7	30.2
	Twist, machine, t.p.i.	16.5	21.9	27.3
	Tension to straighten yarn, g.	2.6	3.2	3.3
45's	Yarn number	43.3	44.4	44.6
	Twist, machine, t.p.i.	20.1	26.8	33.5
	Tension to straighten yarn, g.	2.4	1.7	1.6

* Skein method, ASTM D 180–52T.

† Based on machine settings, allowing for contraction.

‡ Based on Federal Specification CCC-T-191b, Method 4112. Load-elongation curves obtained with Instron Tensile Tester.

3, 4, and 5. Their pertinent properties are given in Table I.

Although the untwist-twist test has been developed with various modifications of specimen length, initial tension, and end point [1*c*, 1*d*, 3, 4, 5, 7, and 11], the method described in ASTM D 180-52T, Section 9*c* [2] for single cotton yarns [1*c*] was followed in this study. A Suter [2] twist tester and the bridge method for manually applying tension were employed. In addition to the 3-g. weight specified in this test, two other tensions were used, namely 156/cotton number g. and grex/20 g. The former, 156/cotton number g., is the tension specified in Federal Specification CCC-T-191b for determining twist in cotton single yarns [5], in ASTM D 39-49 for crimp in yarns taken from fabrics [1*a*], and ASTM D 179-46T for twist in singles of cotton tire cord (1*b*). Grex/20 g., the weight of 500 m. of yarn, was the tension specified in the ISO Third Draft Proposal [8] for determining twist in single spun yarns. (Note: In the Fourth Draft Proposal, dated December 15, 1955, a tension of grex/40 g. is specified.) The calculated tensions for 15's, 30's, and 45's yarns are 10.4, 5.2, and 3.5 g., respectively, for 156/cotton number g.; and 19.7, 9.8, and 6.6 g. for grex/20 g. It will be noted in Table I that these values are all appreciably higher than the tensions found necessary to straighten the yarn, as determined from stress-strain curves, using the Instron Tensile Tester.

The term "machine" or "theoretical" twist is used to indicate the twist inserted in the yarn on the basis of machine calculations, allowing for yarn contraction.

To check this theoretical twist, the different yarns were wound on an evenness board and fifty observations were made on each yarn by counting the turns along the yarn in five 10-in. lengths without untwisting. To aid in counting, a sheet of cross-section paper, on which the distances in inches were clearly marked, was fastened directly under the yarns onto the board. The yarns were then viewed at approximately 7 × magnification through a stereoscopic microscope.

The average values obtained by actual count and by the untwist-twist method using different tensions are shown diagrammatically in Figure 1.

With the exception of the 45's, 3 T.M. yarn, good agreement was found between actual count and the machine twist, considering the variability along the yarn. The coefficients of variation for the 50 in. counted ranged from 12.9% for the 15's, 5 T.M. to 22.7% for the 45's, 3 T.M. yarns. The latter is the yarn just mentioned for its relatively poor agreement with the theoretical. The ranges, moreover, were from 50 to 100% of the average values, indicating that variations along the yarn may be great and worthy of attention when evaluating yarns. Although the number of thick and thin places in these yarns may have been unusually high because of the use of dyed raw stock, similar variations are generally observed in single yarns spun from undyed raw stock.

Because of these large variations in twist found from inch to inch in single yarns, it is suggested that the use of a definite tension in the direct or "parallel-fiber" method may be unwarranted and that the specification of "sufficient tension to straighten the yarn without stretching it" may be adequate.

Tension, on the other hand, has long been recognized as an important factor in the untwist-twist method. At least as far back as 1933, ASTM D 180 contained the requirement: "In making this test, it is essential that check tests be made before proceeding with regular tests in order to determine the proper tension to be placed on the yarn so as not to cause slippage of the fibers and other variations."

As shown in Figure 1, all of the values obtained

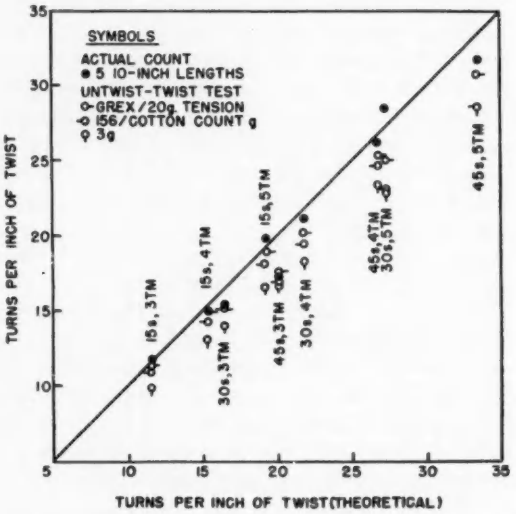

Fig. 1. Turns per inch of twist in cotton single yarns, determined by actual count and by the untwist-twist method using different tensions.

[2] Mention of trade names does not imply their indorsement by the U.S. Department of Agriculture over similar products not mentioned.

in this study were below the theoretical, and the best agreement with the theoretical was established with the highest tension. Both of these findings are illogical if the postulations for the method are correct.

The untwist-twist method is based on the assumption that when the turns of twist in one direction are removed and reinserted in equal amount in the opposite direction, the initially established condition of length or tension will be restored. If strictly true, the total number of turns during the untwist-twist operation divided by two would be the same as the number determined by actual count. It is generally recognized, however, that some slippage of the fibers may occur when the twist is nearly zero; consequently, a larger number of turns per inch would be necessary to restore the initial condition and the value obtained in the test would exceed the number initially present. Since the converse was found another explanation is required.

This behavior can probably be attributed to mechanical strains which have been set up in the twisted yarn and which cause it to resist untwisting and twisting in the opposite direction. It has been suggested [13] that these strains might be overcome in the test by continuing to twist in the opposite direction until about 10% excess twist is inserted and then to remove twist until the original tension and sample length are obtained. Since this procedure would introduce additional uncontrollable variables, it is not suitable for a standard test method.

In this series of tests, the twist values increased as the tension was increased, but none of the tensions tried produced the theoretical twist (Figure 1). This indicates that in these yarns the higher tensions were necessary to overcome mechanical strains, for if their function was merely to straighten the yarn, the higher tensions would be expected to cause a shorter length of yarn to be measured and consequently to give a lower value for twist. With smoother fibers, higher tensions could cause slippage, which in turn would produce higher values. Since tension plays this complex role, finding the "correct tension" to use presents special problems for each particular yarn tested.

For the yarns tested in this study, the least deviation in turns per inch from the theoretical values for twist was found in the 15's yarn and the greatest in the 45's. This relation with yarn number is well illustrated in the three yarns having approximately 20 t.p.i.

A further examination of Figure 1 shows an apparent correlation between the theoretical values and those obtained at each of the different tensions. Since the yarns tested here were similar in construction, this observation indicates that in quality control of yarns of like construction, it might be possible to determine the correlation between values obtained by direct-count and by the untwist-twist methods and then to use the latter method with an appropriate correction factor. However, the validity of this presumption and the practical aspects of such a procedure require further investigation.

Distribution of Twist in a Single Yarn during the Untwist-Twist Test

The mock-grandrelle yarn was especially suitable for observation of what actually happens when a single yarn is subjected to the untwist-twist test.

A 10-in. length of 15's, 5 T.M., yarn was inserted in the twist tester in the usual manner, and the number of turns per inch in each successive inch interval was counted without untwisting. These totaled 197 turns in the Z direction. They were then removed by untwisting to see whether or not all the fibers would be parallel at a condition of "zero twist." As expected, retwisting had begun in places before the initial twist had been completely removed. In fact, 24 turns of Z twist remained and 24 turns of S twist had been inserted. Insertion of twist in the S direction was then continued until 197 turns had been added. When the number of turns in each successive inch was again counted, a somewhat different order of numbers was obtained even though the total count was the same as in the original length but in reverse direction. The appearance of the yarn at these three stages of counting is shown in Figure 2, which also illustrates the nonuniformity of twist along the yarn. The number of turns per inch at each stage is shown in Table II, Section A.

Since the specimen was more taut at the end of the test than it had been originally, a conventional untwist-twist test was performed on another specimen in which the total number of turns required to restore the original tension of the specimen was determined. The initial 10-in. length had a total of 197 turns (coincidental agreement with the first specimen), but only 168 turns in the opposite direction were required to attain the original tension. Consequently, the twist would be reported as 19.7 t.p.i. by the direct method but only 18.2 by the

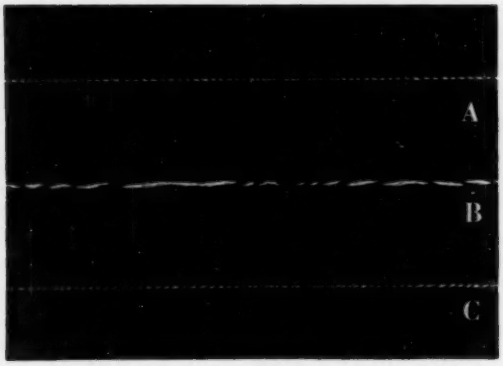

Fig. 2. Appearance of central section of 10-inch length of 15's, 5TM yarn in untwist-twist test: A—197 total turns Z twist; B—"Zero" total twist; C—197 total turns S twist.

indirect method. The distribution of the twist at the beginning and end of this test is shown in Table II, Section B.

Conclusions

The results confirm published and unpublished findings of disagreement between untwist-twist tests and calculations from machine settings or actual counts by a direct-counting method. The behavior of the carded yarns used in this study appears to be comparable to that of woolen yarns for which the Wool Industries Research Association explained similar underestimates by the unsymmetrical nature of the twist-length relation [14]; for when the twist in turns per inch was plotted against specimen length, a steeper gradient was observed on retwisting than during the untwisting operation. Consequently, a low average value was obtained. Worsted yarns, on the other hand, generally give higher values than are obtained with the parallel-fiber method, and this difference is attributed to slippage of the fibers which increases the specimen length. Thus, at least two factors, opposite in effect and varying with different yarns, appear to be operating simultaneously during the untwist-twist test, namely (*a*) torsional effects due to mechanical strains which influence the stress-strain relations and lead to underestimates and (*b*) slippage of fibers which results in overestimates. The agreement between the direct and indirect methods will depend on the extent to which each of these factors operates in the yarn being tested.

Users of the untwist-twist method should therefore be warned not to have false assurance in its reliability because of the reasonably good reproducibility and relatively low range of values obtained. The method is not suited for an acceptance test or a standard procedure, but it may be useful in a qualitative sense when estimates are satisfactory for the purpose or possibly when similar yarns are to be compared after the relationship between the direct and indirect methods has been determined. Even in such applications, however, the limitations of the method should be well recognized. The tension to be used stands out as an important but complex and disconcerting factor in the test, for trial and error methods still appear most satisfactory for its determination.

Direct-counting methods also have limitations because of difficulties in performing them. When specimen lengths longer than the staple length of the fiber are counted by the parallel-fiber method (untwisting), entanglement of fibers may occur, thus making it more difficult to determine when the twist

TABLE II. Distribution of Turns per Inch in Untwist-Twist Test

Counting stage	Direction of twist	Turns per inch along 10-in. length of yarn										Total turns
		1	2	3	4	5	6	7	8	9	10	
A. Total number of turns identical at beginning and end of test (see Figure 2)												
I. Beginning	Z	19	22	23	18	16	23	16	20	21	19	197
II. "Zero"	Z	2	4	2	2	2	5	0	5	2	0	24
	S	1	2	5	3	0	1	3	0	3	5	24
III. End	S	20	24	20	18	16	24	16	22	21	16	197
Difference		1	2	−3	0	0	1	0	2	0	−3	0
B. Total number of turns unlike at beginning and end of test (tension restored)												
Beginning	Z	17	18	22	17	19	24	22	15	25	18	197
End	S	13	15	22	15	15	23	17	13	20	15	168
Difference		−4	−3	0	−2	−4	−1	−5	−2	−5	−3	−29

is completely removed. Specimen lengths shorter than the fiber staple length are more convenient to handle, but because of the variability of twist in short segments along the yarn, it is necessary to exercise extreme care in obtaining a representative sample and to make a large number of observations per sample to obtain a reliable average.

The real need is for more rapid direct-counting instrumental aids which operate as nearly automatically as possible. They should provide means for selecting short lengths and recording the twist observed in short segments as well as the average for the sample. A step toward this goal appears to be represented by the "Rock Bank" single-yarn twist tester, developed by the Fine Spinners & Doublers, Ltd. [6]. They claim that an experienced operator can make about 50 tests in 4 min. The tester provides means for counting ⅓-in. lengths of yarn, using a microscope for magnification.

It is believed that the principle of actually counting the turns of twist in cotton single yarns will remain the basis for the most reliable and suitable method for research and arbitration purposes. Through automation, it is expected that its limitations due to time required and tediousness will be overcome and that the method will become a useful tool for use in routine testing and quality control.

Acknowledgments

The assistance of the members of the Textile Testing Unit, especially W. F. McSherry and H. P. Pastor who made most of the determinations, is gratefully acknowledged. John J. Brown, Cotton Mechanical Processing Section, is due special thanks for the suggestion of using two colors of roving to produce mock-grandrelle yarns and for supervising the spinning of the yarns.

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National Cotton Council of America

Seventh Cotton Research Clinic

The papers in this issue comprise those given at the Symposium on High Production Drawing at the Seventh Cotton Research Clinic of the National Cotton Council of America, held in Pinehurst, N. C., February 15–17, 1956. Other papers presented at the Clinic appeared in the May issue. Reprints of the entire proceedings, bound in a cover, will be distributed through the Cotton Council upon completion of the series.

Some Historical and Technical Aspects of Spinning

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Introduction

This paper will be concerned with a discussion of past, present, and future developments in spinning equipment, rather than with economic and technical aspects as indicated by the title on the program. The economics of spinning is such a big, complex subject that an adequate discussion could consume the entire three days of the Clinic. Likewise, a thorough discussion of technical phases would be time consuming. It seemed advisable to restrict the discussion to some of the problems of spinning, with particular reference to drafting systems and ring and traveler limitations, and to present briefly what research and industry are doing to overcome these problems in order to increase production, lower cost, and improve the uniformity of cotton yarns.

Historical

The art of spinning dates back beyond reliable historical records. It is well known, however, that Egyptian mummies were wrapped in fabrics woven of relatively good quality linen yarns. Possibly these yarns were produced with the distaff and spindle, the first known mechanical device for twisting a series of parallel fibers into a yarn. The soft untwisted fibers were wound on a stick called a distaff, and the spindle was a rod with a notch in the top which held an untwisted strand of fibers. By proper manipulation of the distaff and the spindle, a yarn could be spun and wrapped on the spindle. This crude method of spinning was utilized until about two centuries ago.

In time, a rotating wheel replaced the movement of the operator's arm, and thus was developed the mechanism known as the spinning wheel. A further improvement was the Saxony wheel, said to have been developed about 1540, which used a foot treadle to change reciprocating motion into circular motion. The Saxony wheel represented a considerable advance in the art of spinning.

Historians disagree as to the exact dates of the various developments which have led to modern mechanized spinning, but in general the following appears to be a fairly accurate chronological sequence of events.

There is uncertainty whether John Wyatt or Lewis Paul introduced the idea of roller drafting; however, in 1738 Lewis Paul was granted a patent for roller drafting spinning machinery. About 30 years later James Hargraves developed and patented the spinning jenny which fed out a given length of roving that was held between the spindles and a movable carriage. In operation, the rotation of the spindles inserted twist and the movement of the carriage away from the spindles drafted the strand.

[1] One of the laboratories of the Southern Utilization Research Branch, Agricultural Research Service, U.S. Department of Agriculture.

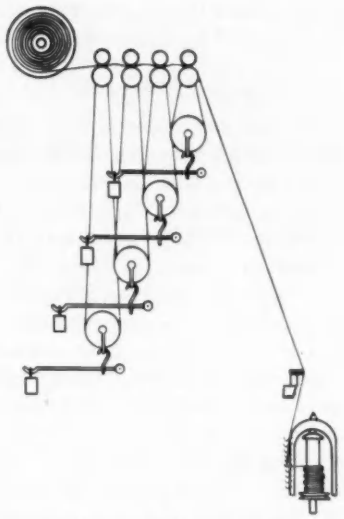

Fig. 1. Principle of Arkwright's spinning machine of 1769.

The predecessor of today's roller drafting spinning frame was the Arkwright spinning frame of about 1769 (Figure 1). This device combined drafting by rollers and twisting by flyers in a multispindle machine. The machine used four sets of drafting rolls which were weighted by dead weights and a lever system. The bottom rolls were wood covered and fluted, and the top rolls were leather covered. Yarn was put on a bobbin by means of a flyer equipped with a series of hooks, called hecks. It was necessary for the operator to stop the machine and place the yarn on successively higher hooks of the flyer in order to wind a bobbin.

As in the case of roller drafting, the exact origin of ring spinning is doubtful, except that it was an American invention. In 1828, Thorp patented a ring concentric with the spindle, and Jenks of Pawtucket, Rhode Island, is credited with inventing the traveler about 1830. Toward the end of the nineteenth century, the ring process was fairly well perfected, and its use was becoming standard throughout the world. Ring spinning is about 250% more productive than mule spinning and is simpler and less expensive to operate.

Early Improvements

Roller drafting has now been known for more than 200 years and ring spinning for more than 100 years; each has attained a high degree of perfection. Basically, however, no real differences in the principle of roller drafting and ring spinning have been developed during this period. At first, three lines of rolls were popular, and innumerable modifications of roll placement, method of weighting, roll design and material, and the like were developed (Figure 2). Later, four lines of rolls were used.

The idea of improving the control of short fibers by increasing the range of contact of the rolls with the fibers led to the invention of the Casablanca, or double apron, system in 1913 (Figure 3, A). Various modifications of double-apron draft systems have also been developed; in general, the trend has been toward replacing the top apron with one or more rolls resting on the bottom apron (Figure 3, B).

A detailed description of the development of long

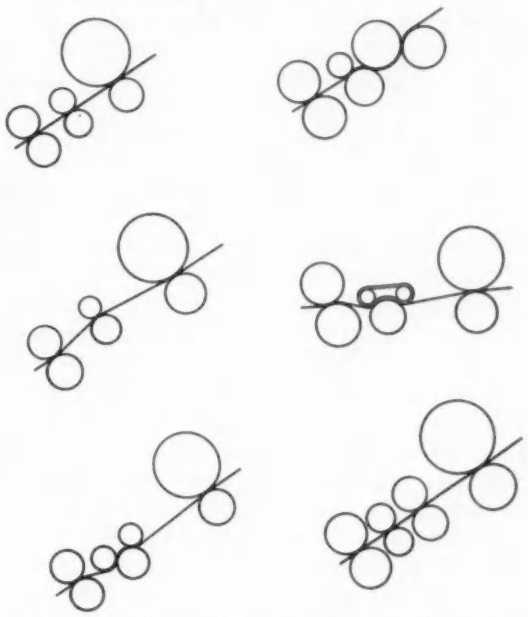

Fig. 2. Examples of roller drafting systems in use after 1900.

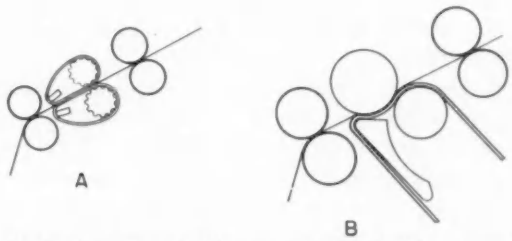

Fig. 3. Apron-type drafting systems: (A) double apron and (B) single apron.

draft spinning is available in an excellent paper published by Jones [18].

From the original wood-covered rolls of the Arkwright frame, bottom rolls progressed through various iron and steel types. Top rolls have been made of all kinds of materials—wood, iron, steel, leather, rubber, and plastics.

Several roll developments through the years may be of interest [4]. The Trumbach top roller was a steel roll circumferentially grooved on the theory that it increased the amount of surface contact with the fibers and thereby assisted in controlling the fibers. For the same reason, soft rubber rolls have been used that were weighted heavily in order to cling over a relatively large part of the bottom roll. Another unique top roll was Meynell's washer top roll which was composed of a series of steel washers free to rotate on a central shaft and also free to move axially. Friction driven, the WTR roll was used as the top middle roll. It was supposed to allow the longer fibers to move forward without interfering with or affecting the movement of the shorter fibers.

The literature has little information on the evolution of the ring and handmade bent-pin traveler that was first used. Apparently there was a gradual improvement of the shape, metallurgy, finish, and lubrication during this period.

Economic Aspects

The modern spinning frame is a mechanical marvel of flexible, trouble-free operation. Long draft systems, larger packages, higher speeds, better materials and construction have vastly improved spinning during the past 25 years. However, the economics of the cotton textile industry have also changed during this time, especially since World War II. The impact of competition from continuous filament yarns, increasing cost of labor and overhead, high cost of cotton and other factors has resulted in increasing attention being devoted to the possibility of developing new methods of spinning or radically changing old methods.

Despite the recent advances in equipment mentioned above, spinning is still the most expensive single process in producing yarn [17]. Depending upon the yarn number and construction, it may cost up to 50% more to put cotton through one spinning process than it does through the combined processes of opening, picking, carding, drawing, and roving. Such a condition exists to a large extent because of the limitations of package size and ring and traveler mechanics; these will be discussed later.

Technical Aspects

As yarn manufacturing technology changes, the demands on spinning equipment are becoming heavier. It is well known that the trend toward fewer doublings and higher drafts places added burdens on the spinning frame. Mills are constantly seeking means for lowering costs by reducing the number of processes. Single creel spinning is replacing double creel spinning; some mills are spinning 90/1 yarn from single creels. Evidence of the remarkably few doublings and the high drafts now being used are shown in a recent study of 17 mills producing print cloth [8]. Summarizing the study, warp yarns were made with a total number of doublings ranging from 12 to 144 and total drafts ranging from 270,587 to 389,055. Similarly, filling yarns were made with 12 to 144 doublings and 379,155 to 4,488,913 drafts. Compare these modern mill organizations with those of only 25 years ago, when two or three processes of drawing and two to three processes of roving were common.

Competition from continuous filament yarns, consumer buying on specifications, and increased attention to the quality of cotton yarns has brought about emphasis on the need for improved yarn uniformity. And because fewer preparatory processes coupled with very high spinning drafts may be conducive to nonuniformity, the spinning frame plays a major part in any attempt to achieve better uniformity.

It is inherent in the design of a mechanical device that further improvement of the device is usually hampered by a few specific obstacles. Once these obstacles are overcome, tremendous strides may be made toward improvement. In the case of the spinning frame, the size of the package is one of the major factors preventing an increase in production. Recent developments by machinery manufacturers may have broken through this barrier and, if so, spectacular changes may be around the corner. In the meantime, however, it is well to consider the types of spinning frames with which most of the cotton textile industry is equipped.

The weight of the package significantly influences production cost, and the spinning bobbin is the smallest package in the yarn mill. Bobbin size and spinning costs are inversely related; doubling the size of the package will usually aid materially in reducing labor costs.

Ring and traveler mechanics limit package size in spinning. Efforts to increase the size of spinning bobbins by using larger rings are limited by the maximum traveler speed. If larger rings are used and spindle speed is reduced to keep traveler speed within acceptable limits, most of the benefits of the larger package are lost. In an attempt to achieve higher speeds, travelers have been designed in many shapes and of a wide range of metals, alloys, and plastics. However, the familiar C-shaped traveler of tempered steel is still the standard.

Lubricated rings are used to reduce friction, and rings have been made of wood, ceramics and other nonmetals. Expedients have been devised such as revolving rings, floating rings, and magnetic spindles to attract the traveler away from the ring. Several of these ideas will be discussed later.

The diameter of the empty bobbin is another factor limiting the amount of yarn which can be put on a bobbin for a given ring size. Experience has shown that if the angle of the yarn from the traveler to the axis of the bobbin is less than 21°, yarn tension is too high and excessive end breakage results. An angle of 27° creates less tension but wastes bobbin capacity. Most spinning frames use an angle of 23° to 26° as a compromise between optimum yarn tension and optimum package size.

Spindle speeds are also responsible for limiting the production of spinning frames. All spindles have inherent modes of vibration, and attempts to operate spindles continuously at speeds greater than 10,000 to 12,000 r.p.m. have not been too successful. High speeds usually cause excessive vibration that may result in excessive ends-down.

Yarn tension is extremely important in any attempt to increase spinning production. Yarn tension is affected by air resistance, traveler weight, traverse length of the bobbin and delivery rate. For example, yarn tension varies widely as the balloon is lengthened and shortened in traversing the bobbin. If the proper weight traveler is used for the shorter balloon length, it will be too heavy for the maximum balloon length. Thus the length of traverse is limited to a span that can be handled adequately by one traveler.

A large part of the effort directed toward achieving constant yarn tension has been concerned with perfecting a variable speed drive for the spinning frame. A variable speed drive helps to maintain relatively uniform tension throughout the spinning cycle and compensates for changes in tension due to the increasing diameter of the bobbin and the changing position of the ring rail. Mechanical and electrical variable speed drives available to date are relatively costly and have not met satisfactorily the economics of American technology, although variable speed motors have achieved limited success in Europe.

Another European technique is to traverse the spindle to build the package rather than to traverse the ring rail. This method does maintain a constant balloon length and therefore aids in producing constant yarn tension. However, the difficulty of driving the vertically moving spindles, extra weight to counterbalance, increased power consumption, and high cost of the equipment has generally discouraged adoption of this method in the United States.

Although there is recent evidence to the contrary, it is generally believed that roller drafting is a principal cause of yarn irregularity because of its failure to control the short cotton fibers. These short fibers are drawn forward by the rolls in groups, rather than individually, and so form thick and thin places. Furthermore, roller drafting places a definite limit on the minimum staple length which can be spun satisfactorily, because of the necessity for separating the rolls by a distance slightly more than the staple length of the cotton in order to minimize fiber breakage. Since it is customary for spinning frames to use rolls of $\frac{7}{8}$ in. or larger diameter, cotton with a staple length of $\frac{7}{8}$ in. or less is not spun under optimum conditions. Apron drafting may alleviate this condition to some extent, but the short fibers are still not under full control.

Regardless of the type of drafting system used, limitations on front roll speed influence the maximum production that can be achieved. Because of the relatively small diameter and long length of the front roll, the driving torque in the roll, the tendency of high roll speeds to establish either intermittent or harmonic vibration, and many other similar mechanical factors, front roll speeds are limited to about 200 r.p.m. Higher speeds would require precision-built rolls, stands, bearings, and other components, and this would, of course, result in increased equipment costs.

Efforts to Overcome Limiting Factors

A number of ingenious methods have been proposed or actually tried in attempts to overcome the various limitations of spinning equipment. To reduce end breakage, many methods for inserting false twist have been devised (Figure 4). Brown [6]

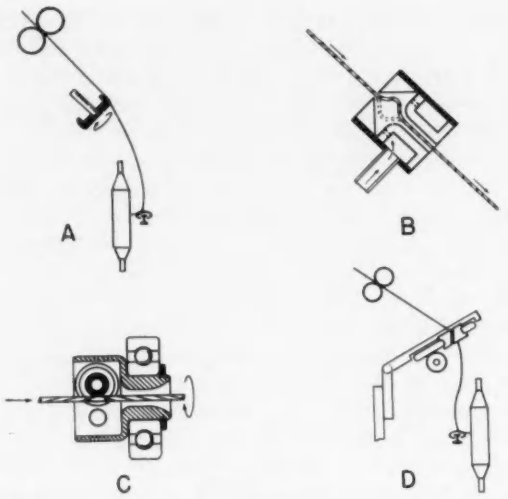

Fig. 4. Device for inserting false twist patented by (A) Brown, (B) Foster, (C) Heberlein, and (D) Hegedüs.

passes the yarn over a small disc or pulley rotating at right angles to the path of the yarn. Foster [11] gives false twist to a yarn through the use of a vortex of whirling fluid such as water or air that rotates about the axis of travel of the yarn. Heberlein [14] snubs the yarn around a freely rotating pulley and then rotates the entire pulley unit. Hegedüs [15] uses a tiny slotted ring-shaped unit driven by rollers and a tape. None of these devices appears to be in widespread use; however, all are relatively new developments.

The ring and traveler have not been overlooked in attempts to improve spinning. Reid [25] patented a spindle made of annular magnets used in conjunction with a ring of nonmagnetic material. As the ring rail traverses, the traveler is subjected to a constant magnetic attraction that tends to draw the traveler toward the spindle and thereby overcome centrifugal force. Friction of the traveler on the ring is decreased, and higher traveler speeds can be utilized.

Blackwood [5] patented a floating ring inside a concave shaped outer spinning ring (Figure 5, A). The yarn passes between the two rings; the inner, floating ring serves as the traveler. Threading up is done through a slot in the outer ring.

Many ideas for balloonless spinning have been tried. From Holland comes the Zoba [2] method which employs an auxiliary twisting device and an extended spindle with several rings integral with the spindle (Figure 5, B). The yarn is wrapped helically around the spindle and comes in contact only with the rings. It is said the rings eliminate the excessive friction heretofore found in systems of this type.

Several years ago, an American textile equipment manufacturer introduced a frame that incorporated a number of features designed to aid in spinning yarn with constant tension. The frame uses conventional drafting systems; however, the drafting rolls are tilted at 60°, and the nip of the front roll is located directly above the spindle. A series of auxiliary rings, or simply "rings" as they are called in the Gwaltney [13] patent, are used to control and stabilize the varying yarn balloon as the ring rail traverses (Figure 6). The top control ring is a pigtail guide, the second ring is nearly as large as the spinning ring and the lowermost ring is slightly larger than the spinning ring. The top two control rings traverse slightly less than the spinning ring, and the bottom control ring traverses the same as the spinning ring. The frame is said to produce economically larger packages of yarn spun at uniform tensions.

Instead of using rings to control tension, Van Riper [28] moved the entire drafting system and thread guides in synchronism with the builder motion and ring rail. The spindles are mounted rigidly. This system has been commercially available on a worsted spinning frame but is said to have been expensive and difficult to maintain.

A new idea in roller drafting is being proposed as a result of scientifically studying the forces acting during the drafting processes. Ambler and Hannah [1] postulate that the irregularities introduced during the drafting process are the result of variation

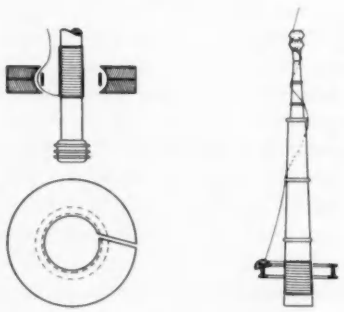

Fig. 5. Method of twisting developed by (A) Blackwood and (B) Zoba.

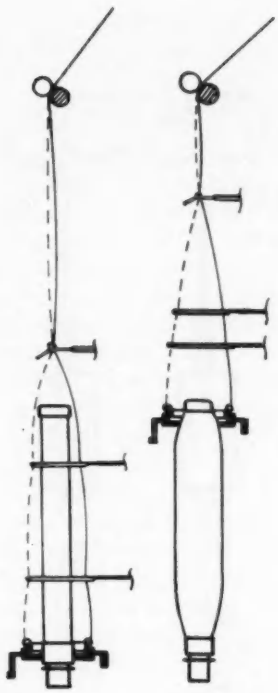

Fig. 6. Principle of the control rings of the Gwaltney spinning frame.

effects and dynamical effects. Variation irregularities are caused by the fibers not gripped by either the front or back roll. Some of these free fibers are apt to be drawn forward out of order, thereby causing thick and thin places in the yarn. Control of the free fibers can be retained only if roving coherence is sufficient to hold the fibers together at all points, and it is difficult to achieve this coherence without excessive tension. Dynamical irregularities are the result of inadequate control of twist and tension in long-draft systems.

As a result of these findings, a unit has been designed which mounts between the front and back rolls (Figure 7). It is comprised of (1) The twist stabilizer, a grooved piece of metal about 1 in. long, which is designed to lead the roving forward and prevent it from rotating and losing twist; (2) the fiber guide, which continues to lead the roving forward; (3) the carrier rollers, 3/10 in. in diameter, which are positively driven at a surface speed slightly greater than that of the back rolls, and (4) the flume, a tapering piece of metal about $\frac{3}{4}$ in. long with a channel of rectangular cross section. The action of the unit is such that it is said to prevent the twist from concentrating in the thinnest places in the strand and thus to allow producing uniform yarn at exceptionally high drafts. Drafts as high as 250 for wool and 110 for cotton have been reported with the unit mounted on a worsted spinning frame.

Another approach to the problem of decreasing manufacturing costs lies in the development of compound drafting systems that will spin directly from heavy roving or from drawing sliver. Efforts along this line are not new; in 1885 Abbot applied roller drafting to spin direct from sliver, and in 1889 Schofield patented a ring and traveler system attached to the card [7]. In the 1930's, Casablanca was experimenting with a compound drafting system comprised of a three-roll drafting zone followed by a Casablanca drafting zone, with a false twist device between the two zones [4] (Figure 8). This unit is similar to several drafting systems now commercially available.

A stumbling block in the adoption of any system for spinning from sliver is the lack of a suitable pack-

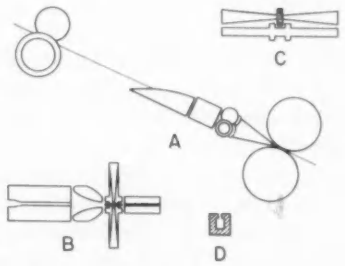

Fig. 7. (A) The Ambler drafting system, (B) twist control unit, (C) flanged carrier rolls, (D) cross section of flume.

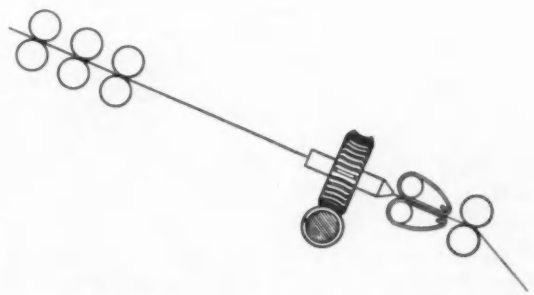

Fig. 8. Compound drafting system developed by Casablanca.

age for the sliver. The size of the standard sliver can is such that it is frequently cheaper to use the roving process than it is to provide the space necessary around direct spinning frames for sliver cans. Hartman [7] has suggested preparing sliver for direct spinning by condensing the sliver with rubbing aprons and packaging it in a cross-ball bobbin.

The Japanese O-M [3] spinning frame attempts to solve the sliver storage problem by using special small cans that hold about 8 lb. of sliver. These cans are mounted down the center of the spinning frame, thus permitting use of both sides of the frame. The drafting system is essentially two Casablanca type systems in tandem (Figure 9, A).

Avondale Mills in 1947 [27] developed a frame capable of drafts up to 600 that spun good quality yarn from sliver (Figure 9, B). However, later studies by this mill revealed that the indicated economies of high draft reached the point of diminishing returns much sooner than anticipated, and therefore further work with the frame was discontinued.

A German frame solves the space problem by placing the sliver cans in a room below the frame and feeding the sliver up through the center of the spinning frame to the back rolls.

In 1949 the Nastrofil [7] system used 7 lines of rolls for spinning from drawing sliver. Total draft was 250, with the draft in each zone being less than 3. The sliver cans were on one side of the frame and the spindles on the other.

A radical approach to achieving large package size is by the centrifugal, or pot spinning, system. Centrifugal spinning is by no means new since patents on such devices date back to 1901. Developed initially for wet spinning of rayon, the process has been adapted to dry packages of rayon and Bradford-type worsted yarn. In centrifugal spinning the yarn is twisted by contact with the inside of a rapidly revolving cylinder and at the same time the yarn is wound on the inner surface of the cylinder where it is held by centrifugal force. In wet spinning the yarn forms into a solid cake which preserves its shape so that it may be easily removed. In dry spinning, however, it is necessary to insert a bobbin into the center of the package and either rewind the package on the bobbin, as is done by Prince-Smith & Stells [30] (Figure 10), or to expand the bobbin to hold the package, as is done in the McCann system [22, 23]. Centrifugally spun yarn is loftier than yarn of the same count and twist from a ring frame. Theoretically, there is no limit to the size package that can be spun, but in practice the size is limited by the rising power consumption as the diameter of the pot is increased. There have been several reports that centrifugal spinning is being experimen-

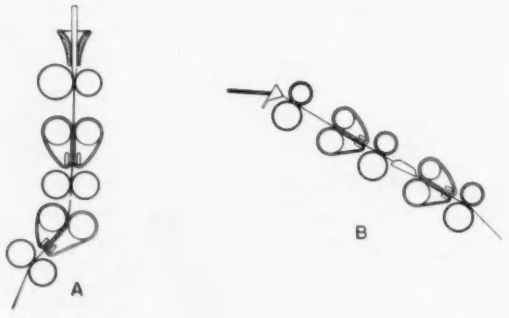

Fig. 9. Compound drafting systems used in spinning from sliver: (A) Japanese O-M frame and (B) Avondale Mills frame.

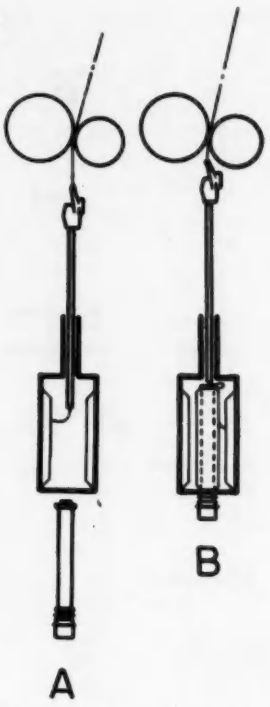

Fig. 10. Prince-Smith and Stells method of centrifugal spinning: (A) yarn being spun and (B) rewinding yarn onto bobbin.

tally applied to cotton yarns, but so far results have not been published.

New Concepts of Spinning

Other methods of twisting and winding yarn are numerous. The Honig [16] and Weiss [29] patents use conventional drafting systems and new methods of twisting (Figure 11). Honig allows untwisted drawing sliver to discharge into a revolving funnel-shaped chamber where the fibers undergo centrifugal action due to the rotation and electrostatic action because the interior of the chamber is coated with hard rubber or glass. The separated fibers converge into a strand at the apex of the funnel and are withdrawn and twisted by means of crossed belts. The yarn is wound on a spool or cheese in a conventional manner. Weiss twists the yarn by a pair of rollers rotating at right angles to their axis; the yarn is threaded down through a sleeve, led out of the upper part and back in the lower part of a cylinder covering the package, and then is wound on the package. The entire assembly rotates around the axis of the spindle.

A patent has recently been obtained on Kyame's [20] idea of spinning by means of a hollow spindle

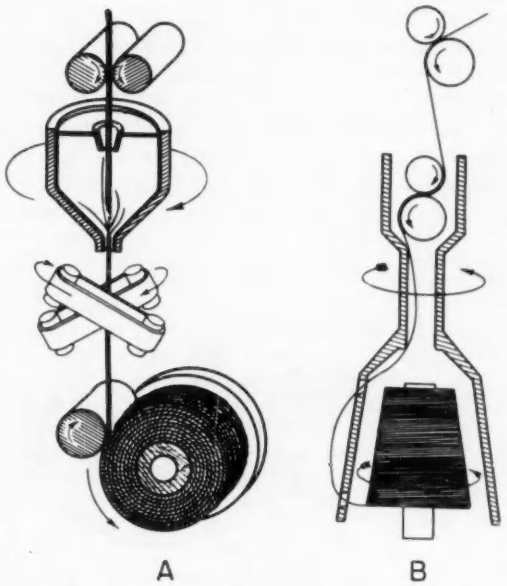

Fig. 11. Method of spinning patented by (A) Honig and (B) Weiss.

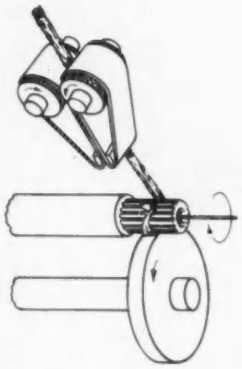

Fig. 12. Method of spinning patented by Kyame.

(Figure 12). The roving is drafted by any standard method and fed to a rotating hollow spindle through a hole at right angles to the axis of the spindle. The roving is fed to the spindle with an intermittent motion synchronized with the speed of the spindle and the production rate of the yarn. It has also been found possible to feed the roving continuously and thereby eliminate the complicated mechanics of intermittent feeding at 10,000-r.p.m. spindle speed. The system permits producing packages of any desired size.

It was mentioned earlier that roller drafting is one cause of yarn irregularity. Nevertheless, except for substituting aprons for rollers, there has been substantially little change in drafting systems since the day of Arkwright's four-roll frame. The development of a method of drafting other than by rolls might conceivably be the key to opening up major advancements in yarn uniformity and production.

Although no commercially practical equipment is yet available, the literature abounds with ideas for forming strands from textile fibers. Oglesby [24] has recently been issued a patent on the application of electrostatic forces to forming a yarn (Figure 13, A). A web of cotton produced by a card or similar device is fed into a chamber wherein electrostatic forces align the fibers. The fibers are withdrawn from the chamber through a hollow guide tube and are twisted by means of a revolving plate equipped with spring clips. The yarn is wound by any conventional means on a bobbin. In order to start the process it is necessary to insert a "seed" yarn into the chamber of oriented fibers. Foster [9, 10] patented a method of drafting wherein two pairs of grippers, one pair above the other, are used in

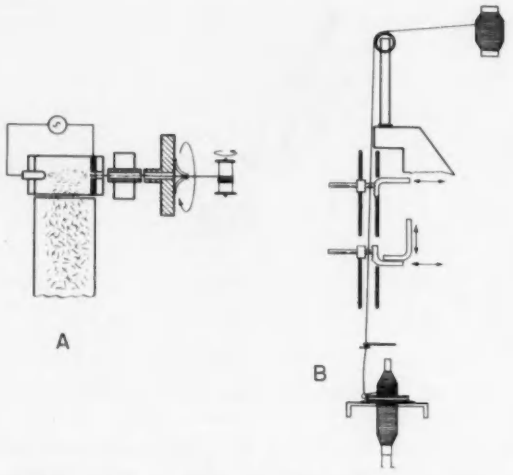

Fig. 13. Method of spinning by (A) Oglesby and (B) Foster.

place of rolls (Figure 13, B). These gripping units seize the strand and attenuate it. The top grippers move a fraction of the distance that the bottom grippers move, the difference between the two is the draft of the machine. Since the distance between the pairs of grippers can be made very small, the system can process short-staple fibers. Although designed originally for asbestos fibers, it has been suggested that the idea might be adapted to cotton.

Gross [12] proposes to remove a sliver from the card by air suction, to discharge the fibers into an air chamber, and then to draft and twist the fibers by combination of centrifugal action and a rotating mechanical device (Figure 14, A). Any size yarn package could be produced by this method.

Mayo [21] envisions pneumatically separating, paralleling and spinning fibers into a twisted yarn (Figure 14, B). His patent comprises an air chamber with an air nozzle that blows the fibers from the bale into a series of chambers (not shown) which ultimately lead to a cyclone where the individualized fibers are subjected to air jets. The aligned fibers are withdrawn from the bottom part of the cyclone, passed through a mechanical twister and wound on a horizontal bobbin.

Both Strang [26] and Keeler [19] have patented methods using the action of fluids (Figure 15). Strang discharges the mixture of fibers and fluid through a relatively small diameter tube. Rotation of the tube establishes a whirling action of the fluid and causes the fibers to migrate to the vortex of the liquid, resulting in twisting the fibers. The fluid is drained from the tube through holes at right angles to the axis of the tube and the yarn is withdrawn and wound in any convenient manner. Keeler places well-opened fibers in fluid-containing chambers and discharges the mixture of fibers and fluid through a narrow orifice onto a wire mesh or other type porous belt. The belt forms a strand of untwisted fibers which are delivered to a subsequent process that may insert a small amount of twist for roving or a larger amount of twist for yarn.

Summary

In summary, it can be said that the last ten years have seen several promising developments that may materially improve the efficiency of cotton spinning. Among these are control rings, a new drafting system, and centrifugal spinning. More radical ideas have been proposed, but apparently none is ready for commercial use. The fact that major changes in spinning are slow in taking place is really a tribute

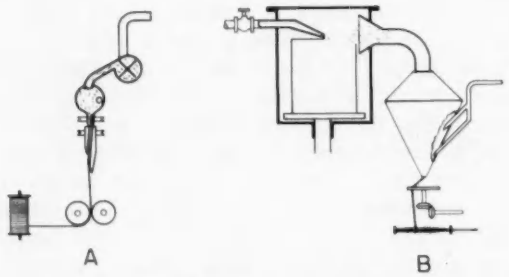

Fig. 14. Method of spinning patented by (A) Gross and (B) Mayo.

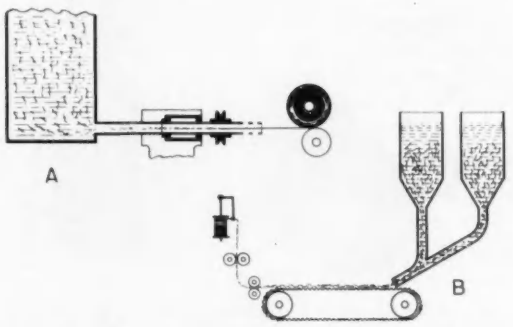

Fig. 15. Method of spinning patented by (A) Strang and (B) Keeler.

to the integrity of the machinery manufacturers who conscientiously and thoroughly evaluate new equipment under actual mill conditions to be sure that the equipment is economically and technically practical for the textile industry.

The future is faced with confidence that modern research and scientific knowledge will soon make available new methods of spinning that will lower the cost and increase the quality of cotton yarns.

Acknowledgment

The authors are indebted to the National Cotton Council of America for generously furnishing much of the material cited, and to a published paper by G. Dakin of the Shirley Institute for information on several of the earlier developments in spinning.

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Improved Cotton Bale Packaging and Its Effects at the Mill

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SIXTY years ago in 1896 the United States Department of Agriculture published a book entitled "The Cotton Plant." In one section of this book is found the following: "Taken altogether it is generally admitted that the American bale is the clumsiest, dirtiest, most expensive and most wasteful package in which cotton, or in fact any commodity of like value, is anywhere put up. It has no friends either among manufacturers, buyers, shippers, insurers, or producers. Custom seems alone responsible for this incubus on the industry." A typical example is shown in Figure 1.

At the Spinner-Breeder Conference at Greenville, Mississippi, in 1954, E. Lord of the British Cotton Industry Research Association had this to say: "In countries abroad it is recognized that America is probably foremost in the art of packaging merchandise for shipment and sale. The eyes of customers in our stores are often quickly attracted to American goods which are both well and attractively packed. In our cotton warehouses also, bales of American cotton are *prominently distinguished* from those of other countries. *But* in this instance, the reason is entirely different. The American practice of repeatedly cutting samples from the sides of a bale at various stages of marketing mutilates the covering which, to start with, is of poor quality. A considerable quantity of cotton is unprotected—some hangs loose, and loss or soiling occurs, while hazards of weather and fire damage are increased.

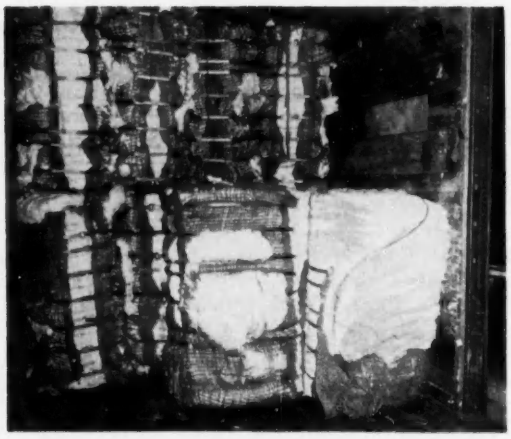

Fig. 1. Regular jute-wrapped bales in car at mill.

"At conferences held half a century or more ago, spinners protested strongly about the condition of American bales. They still complain today and would welcome any improvement in covering bales in accordance with the high standards met in other countries."

Obviously in this 60-year span there has been little improvement of the American cotton bale, although three generations have come along and practically everything else in that period has advanced and improved rapidly.

Although we have had complaints, losses, contamination, and dissatisfaction all these years, why have we permitted the cotton package to remain so poor, and why have we suddenly decided to try to do something about it? Actually it is not so sudden, as there have been sporadic attempts in the past to improve the package. These met with failure for a variety of reasons, such as lack of interest, lack of sustained effort, lack of incentive, questionable handling practices, technical failures of packaging materials, economic obstacles, trading rules, sampling abuses, and others. The reasons for the recently stepped-up campaign to improve the package are rather obvious, such as: greater consciousness of quality and its preservation; intense competition from synthetic fibers; improvements in and greater competition from foreign growth cottons; comparatively poor appearance and sales appeal of American bales, both domestic and abroad; and growing demand from mills for action. While no one would be naive enough to say that American cotton can be sold in world markets mainly on the basis of better protection and neater appearance, it is certainly a

factor which should be corrected, if for no other reason than sound merchandising principles and customer satisfaction.

For these reasons the National Cotton Council in 1952 set up a special industrywide packaging subcommittee to investigate thoroughly the possibilities of developing an improved package, and it is under the direction of this committee that the present work has been carried on. The primary objective is to secure a package which gives maximum protection with reasonable costs. The authorization was broad with only three specifications given; namely, a complete coverage of the bale, accessibility for sampling, and application to existing machinery. Contrary to belief in some quarters, this is not a campaign to eliminate jute. It is purely a campaign to improve the package, and no fibers are barred if they do a satisfactory job at a reasonable cost. Obviously if the job could be done with cotton fibers, it would be that much to the good, but the primary purpose is protection of the bale contents, and for this reason all types of materials are being investigated.

If the objective of a better protected and a better appearing bale is obtained, who would benefit? It is our belief that the entire cotton industry would gain in the total savings due to reduction of such items as contamination, country damage, misshaped and bursted bales, fire, injuries from bands, and other hazards which accompany the cotton bale in its journey from the field to the mill. Freight bills and insurance rates could conceivably be lowered through better packaging. Elimination or reduction of losses mentioned above would add to efficiencies and savings in all segments of the industry, and all would share through the increased competition which cotton could offer at the mill door. It would eliminate the extra cost which many mills are now incurring in the precleaning of bales by blowing off or currying them preparatory to opening. It would decrease the time and waste involved in picking bagging after removal from the bale, and would eliminate completely the danger of getting hard fibers mixed with the cotton, which is a problem in most cotton mills. A good protective covering would reduce the amount of dust which accumulates on cotton between ginning and spinning and should contribute to cleaner opening rooms.

Another advantage which would accrue to the entire industry would be the freight savings involved in the use of a lighter weight cover. The covering material must be shipped from the manufacturer to the distributors and to the gins. It must then be shipped back to the cotton mills on the bales. A substantial reduction in the weight of the cover would cause a substantial reduction in the freight bill to the whole industry. For example, if a plastic cover should prove suitable, which weighed within the range of those included in these tests, namely about 2 lb., the saving would be 10 lb./bale in both directions. This, roughly figured, would amount to about two bales of cotton shipped free in every carload. Another advantage to the industry would be in a cover which is not used a second time on new cotton. It is advisable, from the mill standpoint, to have a cover which will be usable for baling up waste and also for baling dyed raw stock where needed. But the use of secondhand bagging for new cotton is frequently a cause of contamination. The matter of salvage to the spinner is also of importance, but this question is now in a nebulous state. Undoubtedly if new-type covers were used in quantity, some salvage mechanism would be set up. There are, of course, already well-established salvage markets for waste paper, and the salvage value of used polyethylene and vinyl films is quite high in relation to the original cost. The salvage of nonwoven fabrics, or various laminated fabrics, is yet to be determined.

Before all these benefits can be obtained, however, there are many problems to be met and solved prior to the arrival of the bale at the mill.

As mentioned before, earlier attempts at bale improvement proved abortive, but there are new factors on the scene which today enhance the probability of success, such as: technological improvements in packaging materials, cheaper materials and greater manufacturing efficiencies, improvements in presses, improvements in handling, growing consciousness of a need for better sampling methods, slow-up in business activity forcing many manufacturing firms to seek new markets, stepped-up research to engineer new materials specifically for baling instead of the older idea of "make-do," increased consciousness of the power of attractive packages in selling, more manpower and funds to organize and sustain the continuing program without letup; and wholehearted cooperation of the cotton industry and packaging firms in research and field tests.

Within the past year and one-half, about 75 firms in the packaging and allied industries have been ad-

vised of the problems, *and the possibilities for profit,* in supplying the materials for cotton bale packaging. Approximately 20 have responded with covers, bands, and buckles—all of which have been extensively tested. In all this work, proper consideration has been given to such important matters as: application of covers to existing gin equipment, sampling and repair of sample holes, gain or loss in weight in marketing, compressing operations, handling practices, storage effects, wetting and drying-out phenomena, and cost.

While by far the greater part of the work has been concentrated on the covers themselves, we must realize that such items as bands and buckles are also of importance and are being investigated. Broken bands and buckles are serious matters—they not only permit bales to burst open, requiring considerable labor, trouble, and cost to repair, but also are definite injury and fire hazards. Since experiments conducted by the National Cotton Compress and Cotton Warehouse Association indicated that the large majority of burst bales were due to buckle failure in one way or another, two steel companies are currently testing out new type buckles. One of these was distributed extensively this last season, and while there have been some objections to the new type, the general consensus has been in favor of it.

The matter of bands has also been investigated in two ways. Some complaints were received from mills that the present uncoated bands rusted and caused contamination. Objection was raised by some of the railroad people that uncoated bands were more apt to create sparks and cause fires in transit. Two companies submitted coated bands. In laboratory and weathering tests, both lived up to the claims of rust-proofness and spark-proofness, but the cost would be about 20¢ per bale more. It is difficult to justify this additional cost for these somewhat tenuous reasons, and not much interest has been generated.

We have also investigated the possibility of using industrial tapes in place of the steel bands. Experimental tapes with tensiles from 500 to 2,000 lb. were tried and they held very well, although there are some difficulties in applying the bands to the bales. The chief objection is that the tape band might not stand up under fire, in which case the bale would burst open as the bands gave way, and fire would be scattered all over. Bale identification would also be lost. Another application of tapes was in the compress where two tapes were put around the bale to hold it in shape when the steel bands were taken off at the dinky press. In this operation the two bands held the bale so that it could be tumbled into the large press without losing control of the bale or disturbing its shape. This appears to be a feasible operation provided some way can be found to apply the tapes to the bale without undue labor cost. One suggestion, which has worked on a small scale, is to apply four steel bands and two tape bands at the gin so that when the bale arrives at the compress, the tape bands will already be in place and the compress man will simply have to remove these four steel bands and press the bale with the tape bands still on. There are some economic obstacles to this, but it has an interesting approach and we believe more will be forthcoming on this point.

Now we come to the major portion of the work which is that of experimental covers. The traditional open-mesh jute and sugar bagging are quite heavy and very strong. It did not take long to see that if we were stymied by this mental block we would get nowhere fast, as there is no fabric that could be supplied in this weight to even approach jute in low cost. In order to determine, therefore, if such weights and strengths were really essential, we set up a program to determine the qualities needed for a good cover. We purposely went into a wide range of physical properties, even at the risk of approaching the so-called "lunatic fringe." We found early in the experimenting that lighter weight covers with lower strengths had definite possibilities provided the strength decrease was compensated for by an increase in stretch. This opened many new doors and brought in such diverse materials as polyethylene and vinyl films, creped paper, burlaps laminated to paper and to polyethylene, nonwoven fabrics, fiberboard boxes, palma cloth, twisted paper seat-cover fabrics, woven Saran screening, and even zipper-closed duck bags and wire-bound boxes.

As a result of preliminary tests, we narrowed the field down to films, paper, burlap laminates, and nonwoven fabrics for Beltwide large-scale tests. The various cover manufacturers supplied a total of over 6,000 patterns. Before the program could be put into operation, it was necessary to contact the cotton mills to obtain their assurance that they would accept the experimental bales and would pay the difference in the tare, since all of the experimental covers were lighter weight than the standard jute or burlap. This cooperation was obtained very readily, indicat-

ing the great interest within the spinning industry, and incidentally, the best evidence of the great need for a better package. The Commodity Credit Corporation amended its regulations to include the allowance of the tare difference, provided each bale was marked with a tag showing the type of cover and the difference between the actual tare and the normal gross weight of 21 lb. With this groundwork laid, we contacted ginners to secure their cooperation in using these covers. Since, in most cases, the final destination of a bale is unknown at the time of ginning and baling, the job became somewhat complicated, but with the help of all concerned, a program was arranged.

We purposely selected gins scattered from North Carolina to California for several reasons. We felt it would be helpful to secure the ideas of people in all parts of the Belt, and that it was necessary to meet the different problems represented in different areas. For example, outside storage in the West with late Fall rains and fog presents a different problem from outside storage in the Texas Plains where dust is a serious problem. We further wanted to include all the different types of presses and practices extant in the industry, such as flat or low-density bales, compressed bales, and gin standard-density bales. With arrangements completed in 12 different states to the tune of over 6,000 bales, schedules were set up for Council staff members and representatives of the various cover manufacturers to assist the ginners and compressors in any way toward the proper application of the new covers and the follow-up of these bales from the gin through the various marketing channels to the mills.

Next, I will discuss our approach to the various problems, what was and might be accomplished, and discuss briefly our plans for future research. Figures 2 to 10 illustrate several types of experimentally wrapped bales.

Figure 2 illustrates arrival at mill of an experimental shipment of several test bales. This represents the ultimate in appearance and protection. The polyethylene films were not hard to apply at the gin; although in case of windy weather, some difficulty was encountered in placing the film on the press platens properly so that they would not be off-center. The material, being soft and pliable, was easy to fold around the ends and sides of the platen, and to form on the bale. As can be seen, these bales were quite attractive and they stood the compression at the gin very well. Some difficulty was encountered with the

Fig. 2. Experimentally wrapped bales in car at mill.

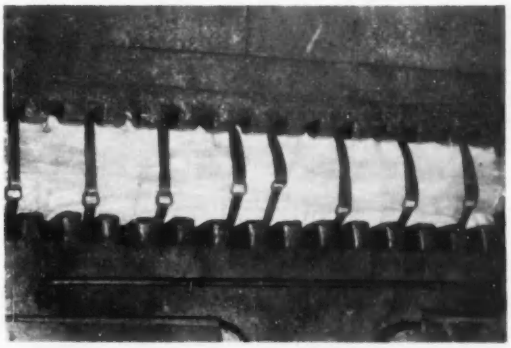

Fig. 3. Polyethylene-wrapped bale in compress press.

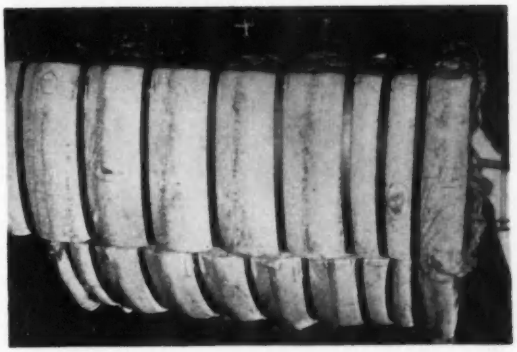

Fig. 4. Polyethylene-wrapped high-density bale.

slippery material holding under the bands in rough handling, and it was tricky to handle at the compress. Note how the cotton and cover are forced into the press channels (Figure 3), indicating the need for stretch. Small blowouts can be seen in the finished bale (Figure 4). No hooks could be used in transfering the bales from the dinky to the large press, and the high speed at which the press ram operates sometimes caused blowouts in the film. Protection from dust, water, oils, and grease was, of course, excellent. Objection was raised, however, that if water did get in either through sample holes or tears, or by condensation between the cotton and the cover, it would not come out, and mildew would result. This was observed in a few cases and leads to the belief that we may require a perforated film in order to allow for vapor transmission. Most of the above remarks apply also to vinyl film.

Creped paper (Figure 5) was very satisfactory from many standpoints, but its chief objection at the gin was its stiffness which made it somewhat difficult to form on the press platens. Two sheets were cut 108 × 54 in. for the top and bottom covers, and two panels, 27 × 48 in., were used to cover the sides. When the bales went to the compress, the two side panels were shifted from the sides to the tops and bottoms to form a full length patch to cover all sample holes, illustrated in Figure 6. When properly done, this starts the bale out fresh and does a good job of protection. The paper was treated for water-resistance on the outside, which shed the water very well. In some cases the bales were completely soaked, but the paper dried out and appeared to be almost as good as new. More important, the cotton underneath was in good condition. The paper

Fig. 5. Paper-wrapped bales on truck.

Fig. 6. Paper-patched bales.

was, however, lacking in tear strength, especially when wet. Protection to grease, oils, and dust was excellent, and this material appeared to hold considerable promise provided a little more flexibility and more tear strength could be built into it. Some experiments are being conducted on the use of linters or motes in the manufacture of paper. Advice from the Forest Products Laboratory in Wisconsin is that the addition of cotton fibers or linters would tend toward increased tear resistance and flexibility.

Two companies participated in tests of fiber board cartons similar to those in which synthetic fibers are shipped. There is no question that these cartons are very tough and will stand a lot of handling. They were, however, quite difficult to get into the gin boxes for filling and the bales were difficult to sample. Some of the cartons did not stand up well at all in the compressing, but were cut into strips by the press, since they did not have enough stretch. One type did stand the compression fairly well, and although showing some cracks, it did produce a well-

Fig. 7. Nonwoven cotton-wrapped gin bales.

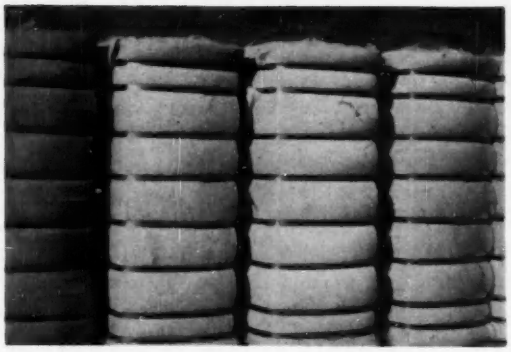

Fig. 8. Assorted experimentally wrapped bales, standard density gin press; l to r, fiber board, two nonwoven cotton, polyethylene.

protected bale. The extra tare, however, on this carton, and the difficulties in applying it at the gin, as well as in sampling, are serious objections to its use at the present time. Further research on design is needed in this field.

Several different weights of burlap laminated with paper, and with polyethylene film were used. Partly because of the general familiarity with burlap covers, and partly because of its greater tear resistance, the burlap-laminates appeared to meet with the most popular approval. This does not necessarily mean nor imply they are the best, all things considered. We found that the 12-oz. burlap was about the irreducible minimum to withstand compression. Some breaks were obtained in the burlap at this weight, but in those cases the polyethylene film underneath did not break, but stretched, and the cotton was still protected. Hooks could be used in the burlap for the transfer from the dinky press to the large press and this was, of course, one of its strong points with respect to the compress operations. Hand hooks will tear burlap as they will tear other things, but in general the burlap-laminates withstood rough handling somewhat better than most of the other materials.

The final field on which considerable emphasis was put was that of nonwoven fabrics. In years past, attempts have been made to use woven cottons either in a net-type fabric, or in a duck fabric. None of these were too successful, primarily because of high

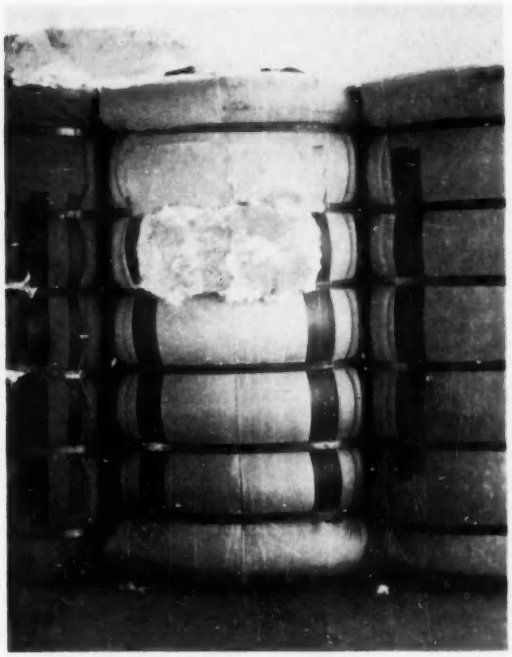

Fig. 9. Nonwoven cotton-wrapped bale showing built-in flap for covering sample hole.

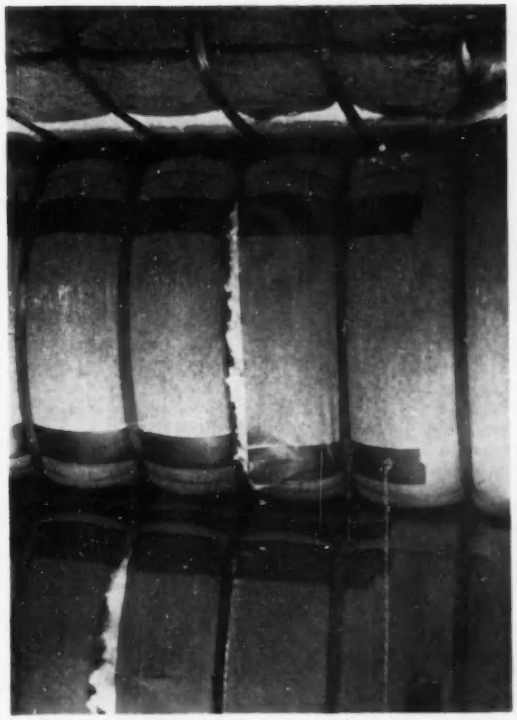

Fig. 10. Same as 9, but with sample hole closed.

cost. In the nonwoven field, however, some possibilities were noted because of lower cost than woven fabrics. Figures 7 to 10 show some nonwoven cotton–wrapped bales. Three different types of nonwovens were tried. One was composed largely of a synthetic fiber mixed with cotton, another with high cotton content, and the other with 100% cotton fiber. All these types did quite well at the gin and made very attractive bales, which aroused favorable comment. The styles with high cotton and all-cotton content had weight and drape to them to approximate woven fabrics. Their tear strengths were not quite adequate, but their chief drawback was lack of ability to withstand the terrific pressures at the compress. In an earlier experiment, the all-cotton fabric of a lighter weight performed better than the later one which was much heavier. I do not know the explanation of this, but we do want to go back to the original one and try again. The high synthetic content cover was lightweight and withstood all compressions, but cost is out of line. The nonwoven fabrics absorbed moisture very readily and they dried out quickly provided there was sunshine; but in those tests where continued rain and heavy fogs prevailed, the nonwoven fabrics dried out slowly and some mildew damage to the cotton was reported. Protection against dust and grease was quite good. Considerable interest was aroused with the nonwoven cotton covers, because of the potential use of 125,000 to 200,000 bales of low grade, short staple, low Micronaire cotton which might be utilized for cotton bale covers. Woven fabrics should not be fully ruled out, as economics in the manufacture of a net-type fabric with some lamination might bring them into line costwise.

Tables I through III summarize in adjective form the relative performances of the various materials at the gin, compress, and mill. It should be pointed out that at the gin and the mill you will note a higher percentage of Good and Very Good ratings for the experimental covers than at the compress. The reverse is true for the jute and sugar bagging. This is because at the compress the problems are primarily those of handling, and we have several problems at this point which have not yet been solved.

TABLE I. Performance of Cotton Bale Covers at Gin

Item	Experimental Materials				Customary Materials	
	Burlap laminates	Non-wovens	Paper	Plastics	Jute	Sugar
Weight, lb. per cover	8	5	8	2	12	12
Size, yd.²	12	12	12	12	8	8
Strength	Good	Fair	Good	Poor	V. Good	V. Good
Stretch	Poor	Fair	Good	V. Good	Poor	Poor
Main fiber content	Jute-Paper Jute-Poly.	Cotton and Synthetics	Paper	Polyethylene Vinyl	Jute	Jute
Application ease						
a. Two sheets	Fair	Good	Poor	Good	V. Good	V. Good
b. Four sheets	Good	Good	Good	Fair	—	—
Compression resistance	V. Good	Good	Good	V. Good	V. Good	V. Good
Handling bales						
a. Hooks	Good	Poor	Fair	Poor	V. Good	V. Good
b. Hand	Good	Poor	Fair	Poor	V. Good	V. Good
Identification (tags)	V. Good	Poor	Fair	Poor	V. Good	V. Good
Sampling						
a. Cutting	Good	Good	V. Good	V. Good	Poor	Fair
b. Repair	Poor	Fair	Poor	Fair	Poor	Poor
Storage						
a. Water shedding	Good	Poor	Good	V. Good	Poor	Poor
b. Drying out of cotton	Poor	Fair	Fair	Poor	V. Good	Fair
c. Dust resistance	V. Good	V. Good	V. Good	V. Good	Poor	Fair
d. Weight gain and loss	Poor	Fair	Fair	Poor	V. Good	Good
e. Grease and oil resistance	V. Good	Fair	Good	V. Good	Poor	Poor
Re-use potential	Fair	Poor	Poor	Poor	Fair	Fair
Protection	V. Good	Good	V. Good	V. Good	Poor	Fair
Appearance	V. Good	V. Good	V. Good	V. Good	Poor	Fair
Cost per square yard	Competitive Range	Competitive Range	Competitive Range	Lower	Standard	Standard

Obviously, one of the greatest drawbacks in the field of better packaging is that of sampling. Even if a perfect cover were developed, it would be greatly minimized in its advantages due to the repeated sampling which occurs, with no effort to close up the sample hole. As an effort to accomplish something along this line, we enlisted the aid of several industrial tape companies who furnished us with various types of pressure-sensitive tapes. Tapes held fairly well on film and on non-woven fabrics, but did not do too well on the paper or on the burlap. The biggest problem here, however, is to get the tapes used. For this reason we experimented with the idea of incorporating tape at the factory. In this idea we made two slits lengthwise in the pattern and put a piece of 3-in. tape over the slits. This was then put onto the bale, and the sampler cut crosswise through the cover and tape. This created a rectangular flap which could be lifted up and after the sample was taken out, could be pulled down tight

TABLE II. Performance of Cotton Bale Covers at Compress

	Experimental Materials				Customary Materials	
Item	Burlap laminates	Non-wovens	Paper	Plastics	Jute	Sugar
Handling						
a. Hook	Good	Poor	Fair	Poor	V. Good	V. Good
b. Hand	Good	Poor	Fair	Poor	V. Good	V. Good
c. Machine	Good	Fair	Fair	Fair	Good	Good
Identification (tags)	V. Good	Poor	Fair	Poor	V. Good	V. Good
Sample Cutting	Good	Good	V. Good	V. Good	Poor	Fair
Storage						
a. Drying out	Poor	Fair	Fair	Poor	V. Good	Fair
b. Tar, oil, and grease resistance	V. Good	Fair	Good	V. Good	Poor	Poor
c. Dust resistance	V. Good	V. Good	V. Good	V. Good	Poor	Fair
d. Weight gain and loss	Poor	Fair	Fair	Poor	V. Good	Good
Compression						
a. Unbanding	V. Good	Fair	Good	V. Good	V. Good	V. Good
b. Dinky transfer	Good	Poor	Poor	Poor	Good	V. Good
c. Patching	Good	Fair	Good	Fair	Poor	Good
d. Pressing	Good	Poor	Good	Fair	V. Good	V. Good
e. Head forming	Good	Good	Good	Good	Poor	Fair
Fire resistance	Good	Good	Good	V. Good	Poor	Poor

TABLE III. Performance of Cotton Bale Covers at Mill

	Experimental Materials				Customary Materials	
Item	Burlap laminates	Non-wovens	Paper	Plastics	Jute	Sugar
Appearance	Good	Fair	Good	Fair	Poor	Poor
Handling						
a. Hook	Good	Poor	Fair	Poor	V. Good	V. Good
b. Hand	Good	Poor	Fair	Poor	V. Good	V. Good
c. Machine	Good	Fair	Fair	Fair	Good	Good
Sampling	Good	Good	V. Good	V. Good	Poor	Fair
Storage (mildew)	Poor	Fair	Fair	Poor	V. Good	Good
Reduction of contamination	Good	Good	Good	Good	Poor	Poor
Precleaning bales	V. Good	Good	Good	V. Good	Poor	Poor
Waste cotton	V. Good	Good	Good	V. Good	Poor	Poor
Opening						
a. Picking bagging	V. Good	Good	V. Good	V. Good	Poor	Poor
b. Picking lint	Good	Good	V. Good	V. Good	Poor	Poor
c. Positioning opened bale	Good	Fair	Fair	Poor	V. Good	V. Good
Re-use						
a. Waste baling	Good	Poor	Poor	Poor	Good	Good
b. Dyed stock baling	Good	Poor	Poor	Poor	Good	Good
Salvage	Good	Poor	Poor	Good	Good	Good

and resealed by the strips of tape overlapping the edges of the flap. This is far from perfect, but it has promise, not only because it would be put on at the factory and be supplied with the cover, but it would be available on the bale when needed. Although tape may not be the final answer on this, the idea of some sort of closure is not fantastic and might be worked out. Certainly if bales are continued to be cut, it will take some effort on somebody's part to close them, if this is ever to be done. One cannot expect to make improvements without making effort.

Several hundred of the bales have arrived at cotton mills and reports are now coming in. In general they are good, especially with respect to the performance of the covers themselves, if one makes allowance for the sampling practice. A very incomplete tabulation shows 87% of bales arrived at mills in better condition than those wrapped in jute or burlap, and the open sample holes were not embedded with strings or particles of jute fiber. Opening room workers advised that 66% of the bales had no need for picking the bagging when removed from the bale and, of course, no harsh fibers were embedded in the cotton. Seventy-eight percent of the experimental bales needed no precleaning before opening. Heads were well protected in 82% of cases. Contamination and waste were reduced in 74% of the test bales, and labor savings in the opening room were reported for 63% of the bales. There was not a sufficient number of bales in any one mill to make a thorough study of the reduction of tar spots. This is a type of test which could easily run aground if not properly controlled all the way from the field through the gin and into the mill.

In summarizing the program, I would say it is still in the research stage. All of the covers used in the program have good features and poor features. We need to combine the good ones into one cover, either through a new material, or through laminations or combinations of one kind or another. We believe it can be done, and at a cost which is in line with the work expected of it. Speaking of cost, we must bear in mind that the present types of covers include only about 8 yd.^{2} of material, whereas to do the job properly and get complete coverage, it will require 12 yd.^{2} This factor must be considered in discussing comparative costs.

Another point of considerable importance in maintaining interest and continuing the program is some positive declaration from the various segments of the cotton industry of their intention to adopt the new cover when one is perfected. There is not much incentive for the packaging people, or anyone else, to spend their time and money in developing a satisfactory package if there is doubt that it will be accepted.

While no decision need be made today, it is not too early to be thinking of two other matters which must be faced squarely at some time in the future. First, there is the practice of gross weight trading. If a satisfactory lighter weight cover is developed, either the tare allowance would have to be lowered or net weight trading instituted. Cotton going to foreign countries is sold on net weight, and the American extra-long staple cottons are sold domestically on this basis. The plans for the coming year include a thorough study of this particular subject.

The second problem, which has already been discussed, is that of sampling. No more need be said, except that this matter will also be thoroughly studied and experimented with in the future program.

In closing, I would again like to thank all those who have contributed so generously with their time, money, and encouragement in this project.

We believe real progress has been made. The Council solicits your cooperation, and we stand ready to do anything possible to assist both the packaging industry and the textile industry in consultations, liaison, and field tests designed to further the progress of better bale packaging. A potential annual market of 150,000,000 yd.^{2} of covering material, 100,000,000 ft. of patching tape, and 900,000,000 ft. of high-strength banding tape await the packaging industry. A potential new use for 200,000 bales of cotton, if a cotton cover is developed, reduction of losses in contamination and handling, substantial freight savings, and pride in its product await the cotton industry. Are these goals worth working for?

Cotton Fiber Bundle Elongation and Tenacity as Related to Some Fiber and Yarn Properties[1]

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Introduction

The elongation of cotton, either under continuously varying load or at breaking load, has been investigated by a number of workers. Attempts have been made to relate the extension properties of single fibers and yarns to the structure and behavior of cotton and its products [2, 3, 4, 6, 7, 8]. The ability of the Stelometer [5] to make rapid determinations of the breaking extension and load of fiber bundles, and to indicate the percent elongation at break with a standard deviation of less than one part in ten, made it seem desirable to compare percent elongation with processing and yarn properties of a large number of cottons grown under different environments during different crop years, and on which some processing and yarn data were available. Since the shapes of load-extension curves for cotton are generally similar, varying mainly in slope and distance to the break point, it is felt that the end point of the curve given by tenacity and elongation at break is almost as useful as the complete curve.

Materials and Methods Used

The material used in this study consisted of 139 cottons from the 1951 crop, 252 cottons from the 1953 crop, and 289 cottons from the 1954 crop, all being taken from the respective Annual Varietal and Environmental Studies conducted and reported on by the Field Crops Research Branch of the Agricultural Research Service [9, 10, 11]. A bulk sample of each raw cotton was first blended on a miniature card to improve homogeneity. These blended samples then went through the laboratory twice as first and second runs for Stelometer determinations.

Two sets of Pressley jaws, two operators, and two Stelometers were employed in making the tests. Both instruments were compensated for the dependence of elongation scale reading on sample size, automatically correcting the scale reading to what it would have been at zero load. In each of the two runs, two sets of readings of T_0 and E_0 were made on one instrument, while two sets of readings of T_1 and E_1 were made on the other.

T_0 = tenacity in g./grex at zero jaw spacing
E_0 = elongation scale reading at zero jaw spacing
T_1 = tenacity at $\frac{1}{8}$-in. jaw spacing
E_1 = elongation scale reading at $\frac{1}{8}$-in. jaw spacing

Between runs, the sets of jaws and Stelometers were interchanged so that the jaws and Stelometer used to measure T_0 and E_0 during the first run were used for T_1 and E_1 during the second.

Tenacity in grams per grex was computed by multiplying breaking load in kilograms by specimen length in centimeters and dividing by specimen weight in milligrams. The calibration of the elongation scale was such that as the elongation indicating needle responded to an increase in the distance between the jaws, the scale reading expressed that increase in terms of percentage of $\frac{1}{8}$ in. As a result, subtracting E_0 from E_1 would be one possible way of correcting for stretch within the jaws and obtaining percent elongation at break. This is the way all elongation data on the 1951 and 1953 crops were handled. This procedure was based on the assumption that the slippage in the jaws for a given cotton at a given breaking load is the same for the two gauge lengths.

Before the cottons of the 1954 crops were measured, a slightly better procedure for correlating Stelometer elongation determinations with other cotton properties was found. The variability of percent $E = E_1 - E_0$ is noticeably affected by the rather large coefficient of variation of E_0 (over 20%). In Table I are listed coefficients of correlation between

[1] A report of work done under contract with the U.S. Department of Agriculture and authorized by the Research Marketing Act. The contract was supervised by the Southern Regional Research Laboratory, Southern Utilization Research Branch, Agricultural Research Service.

first-run and second-run values of E_1 and percent E for the 1953 and 1954 cottons. It will be noticed that E_1 is distinctly more reproducible than is percent E. This is to be expected since E_1 is subject to only one measurement error and $E_1 - E_0$ is subject to two. For correlation purposes, therefore, E_1 is superior to $E_1 - E_0$. To correct for slippage, it would probably be better to subtract some average value of E_0 since individually determined E_0's have so large a coefficient of variation. This treatment would be equivalent to assuming that slippage in the jaws at a given breaking load is the same at both gauge lengths for all cottons. Another way to correct for slippage would be to multiply E_1 by a constant, which would be equivalent to assuming that the effective gauge length of the slipping fibers within the jaws is the same at the same breaking load for all cottons. This method for correcting E_1 to percent elongation is believed to be the best of those tried so far, since the correlation between E_1 and E_0 is fairly high, usually yielding a coefficient of about 0.60. The best value of the constant to multiply by E_1 seems to depend

TABLE I. Correlation Coefficients. First Run versus Second Run. 1953 and 1954 Annual Varietal and Environmental Spinning Studies

	No. of samples	E_1 vs. E_1	% E vs. % E
Long staple cottons, 1953	78	0.92	0.81
Medium staple cottons, 1953	174	0.69	0.50
Long staple cottons, 1954	95	0.85	0.65
Medium staple cottons, 1954	194	0.79	0.55

TABLE II. Simple, Multiple, and Partial Correlation Coefficients Computed from Measurements on Cottons from Three Crop Years

	American-Egyptian long staple			Other long staple				All long staple			Medium staple			Weighted average
	1951	1953	1954	1951	1953	1954	1954A	1951	1953	1954	1951	1953	1954	
No. samples	13	30	21	22	48	25	49	35	78	95	104	174	194	
99% Conf.	0.68	0.46	0.55	0.54	0.37	0.51	0.36	0.43	0.29	0.26	0.25	0.19	0.18	
95% level	0.55	0.36	0.43	0.42	0.28	0.40	0.28	0.33	0.22	0.20	0.19	0.14	0.13	
						Part A								
EY	−0.19	0.11	−0.24	−0.50	−0.63	−0.81	−0.54	−0.13	0.15	−0.25	−0.28	−0.14	0.14	−0.15
ET_0	−0.25	−0.01	−0.67	−0.58	−0.76	−0.78	−0.78	−0.41	−0.17	−0.58	−0.60	−0.50	−0.70	−0.55
YT_0	0.74	0.74	0.79	0.86	0.77	0.95	0.86	0.77	0.84	0.87	0.71	0.63	0.38	0.68
$E \cdot YT_0$	0.25	0.17	0.82	0.58	0.76	0.81	0.82	0.50	0.54	0.77	0.63	0.55	0.82	0.66
$Y \cdot ET_0$	0.74	0.75	0.89	0.86	0.78	0.96	0.89	0.79	0.88	0.92	0.73	0.66	0.67	0.76
$T_0 \cdot YE$	0.75	0.75	0.94	0.87	0.85	0.95	0.94	0.83	0.88	0.95	0.82	0.76	0.85	0.85
$EY \cdot T_0$	−0.01	0.17	0.65	−0.01	−0.11	−0.32	0.39	0.31	0.52	0.63	0.25	0.26	0.60	0.36
$ET_0 \cdot Y$	−0.17	−0.13	−0.81	−0.34	−0.55	−0.08	−0.72	−0.48	−0.53	−0.76	−0.59	−0.54	−0.82	−0.61
$YT_0 \cdot E$	0.73	0.75	0.88	0.80	0.58	0.88	0.83	0.79	0.88	0.92	0.70	0.65	0.67	0.74
						Part B								
EY	−0.19	0.11	−0.24	−0.50	−0.63	−0.81	−0.54	−0.13	0.15	−0.25	−0.28	−0.14	0.14	−0.15
ET_1	−0.21	−0.02	−0.31	−0.41	−0.60	−0.77	−0.50	−0.02	0.19	−0.13	−0.24	−0.22	0.05	−0.16
YT_1	0.90	0.82	0.85	0.84	0.86	0.96	0.92	0.91	0.95	0.95	0.82	0.86	0.86	0.88
$E \cdot YT_1$	0.21	0.22	0.31	0.50	0.64	0.81	0.54	0.28	0.23	0.41	0.28	0.24	0.19	0.31
$Y \cdot ET_1$	0.90	0.83	0.85	0.86	0.87	0.96	0.93	0.92	0.95	0.96	0.82	0.86	0.87	0.89
$T_1 \cdot YE$	0.90	0.83	0.86	0.84	0.86	0.96	0.92	0.92	0.95	0.96	0.82	0.83	0.87	0.88
$EY \cdot T_1$	0.00	0.22	0.04	−0.32	−0.29	−0.37	−0.24	−0.27	−0.12	−0.39	−0.15	0.09	0.18	−0.06
$ET_1 \cdot Y$	−0.09	−0.19	−0.20	0.23	0.13	0.00	−0.01	0.24	0.17	0.34	0.03	−0.21	−0.13	−0.01
$YT_1 \cdot E$	0.89	0.83	0.84	0.80	0.78	0.89	0.89	0.91	0.95	0.95	0.80	0.83	0.86	0.86
						Part C								
EY	0.11	0.11	−0.24	−0.50	−0.63	−0.81	−0.54	−0.13	0.15	−0.25	−0.28	−0.14	0.14	−0.15
EX	0.92	0.87	0.80	0.74	0.87	0.85	0.85	0.74	0.66	0.83	0.81	0.66	0.84	0.78
YX	0.11	0.02	−0.46	−0.73	−0.73	−0.95	−0.76	−0.49	−0.48	−0.61	−0.42	−0.43	−0.04	−0.40
$E \cdot YX$	0.92	0.88	0.82	0.74	0.87	0.85	0.87	0.79	0.85	0.90	0.82	0.68	0.86	0.82
$Y \cdot EX$	0.11	0.19	0.51	0.74	0.73	0.95	0.79	0.60	0.78	0.78	0.43	0.47	0.33	0.54
$X \cdot YE$	0.92	0.87	0.85	0.85	0.90	0.96	0.92	0.84	0.88	0.93	0.84	0.74	0.86	0.85
$EY \cdot X$	0.03	0.19	0.24	0.10	0.03	0.05	0.31	0.40	0.71	0.61	0.10	0.21	0.33	0.30
$EX \cdot Y$	0.92	0.87	0.80	0.64	0.78	0.47	0.80	0.78	0.84	0.89	0.80	0.67	0.86	0.79
$YX \cdot E$	0.02	−0.16	−0.46	−0.62	−0.48	−0.86	−0.68	−0.59	−0.78	−0.76	−0.33	−0.45	−0.30	−0.48

slightly on which pair of Pressley jaws is used but has an average value close to 0.80.

The processing and yarn data compared with Stelometer readings of tenacity and elongation consisted of yarn appearance, percent picker and card waste, nep count, skein strength and X-ray angle, all of which were obtained from the Annual Varietal and Environmental Spinning Study Reports [9, 10, 11], except the 1951 and 1953 X-ray angle values which were furnished as unpublished data by the Plant Industry Station of the Agricultural Research Service, Section of Cotton and Other Fiber Crops. In addition, yarn-elongation data were available for a few of these cottons which had been included in studies by Brown [1] and Wakeham [12]. A preliminary graphical survey showed that the only available properties recognizably associated with Stelometer readings were skein strength, X-ray angle, and yarn elongation. Since yarn elongation was available for only a small number of samples, it was not included in the extended correlation analysis described below.

Results and Discussion

The correlations computed for the 680 cottons are displayed in Table II, parts A through F. For each crop year, the cottons were divided into two groups: medium staple cottons and long staple cottons. The long staple groups were subdivided into two groups: American Egyptians and others. Finally, the 1954 group of long staples other than American Egyptian was further subdivided into two groups: those spun into combed yarns only and those spun into both combed and carded yarns. The latter group is desig-

TABLE II. (Continued)

	American-Egyptian long staple			Other long staple				All long staple			Medium staple			Weighted average
	1951	1953	1954	1951	1953	1954	1954A	1951	1953	1954	1951	1953	1954	
No. samples	13	30	21	22	48	25	49	35	78	95	104	174	194	
99% Conf.	0.68	0.46	0.55	0.54	0.37	0.51	0.36	0.43	0.29	0.26	0.25	0.19	0.18	
95% level	0.55	0.36	0.43	0.42	0.28	0.40	0.28	0.33	0.22	0.20	0.19	0.14	0.13	
							Part D							
ET_0	−0.25	−0.01	−0.67	−0.58	−0.76	−0.78	−0.78	−0.41	−0.17	−0.58	−0.60	−0.50	−0.70	−0.55
ET_1	−0.21	−0.02	−0.31	−0.41	−0.60	−0.77	−0.50	−0.02	0.19	−0.13	−0.24	−0.22	0.05	−0.16
T_0T_1	0.79	0.71	0.79	0.85	0.88	0.96	0.82	0.70	0.86	0.81	0.78	0.68	0.44	0.71
$E \cdot T_0T_1$	0.25	0.02	0.76	0.86	0.77	0.78	0.81	0.55	0.67	0.81	0.69	0.53	0.80	0.68
$T_0 \cdot ET_1$	0.79	0.71	0.91	0.89	0.93	0.97	0.92	0.80	0.92	0.94	0.88	0.77	0.84	0.86
$T_1 \cdot T_0E$	0.79	0.71	0.85	0.86	0.89	0.96	0.85	0.76	0.92	0.91	0.82	0.69	0.67	0.78
$ET_0 \cdot T_1$	−0.14	0.01	−0.73	−0.49	−0.61	−0.23	−0.74	−0.55	−0.66	−0.81	−0.67	−0.50	−0.80	−0.63
$ET_1 \cdot T_0$	−0.02	−0.02	0.49	0.21	0.24	−0.10	0.38	0.41	0.66	0.71	0.44	0.19	0.52	0.40
$T_0T_1 \cdot E$	0.77	0.71	0.83	0.83	0.82	0.91	0.80	0.76	0.92	0.91	0.81	0.67	0.67	0.77
							Part E							
ET_0	−0.09	−0.01	−0.67	−0.58	−0.76	−0.78	−0.78	−0.41	−0.17	−0.58	−0.60	−0.50	−0.70	−0.55
EX	0.92	0.87	0.80	0.74	0.87	0.85	0.85	0.74	0.66	0.83	0.81	0.66	0.84	0.78
T_0X	−0.26	−0.13	−0.81	−0.88	−0.88	−0.97	−0.95	−0.79	−0.71	−0.88	−0.80	−0.78	−0.84	−0.79
$E \cdot T_0X$	0.93	0.88	0.80	0.75	0.87	0.87	0.86	0.79	0.79	0.90	0.82	0.66	0.84	0.81
$T_0 \cdot EX$	0.46	0.25	0.81	0.88	0.88	0.97	0.96	0.83	0.82	0.92	0.81	0.78	0.84	0.82
$X \cdot T_0E$	0.94	0.88	0.88	0.92	0.93	0.98	0.97	0.91	0.90	0.97	0.90	0.84	0.91	0.91
$ET_0 \cdot X$	0.39	0.21	−0.06	0.21	0.02	0.33	0.21	0.41	0.57	0.59	0.15	0.03	0.03	0.20
$EX \cdot T_0$	0.93	0.88	0.60	0.59	0.66	0.61	0.58	0.74	0.78	0.84	0.70	0.50	0.66	0.67
$T_0X \cdot E$	−0.45	−0.25	−0.61	−0.82	−0.67	−0.93	−0.88	−0.79	−0.81	−0.88	−0.67	−0.69	−0.65	−0.71
							Part F							
ET_1	0.07	−0.02	−0.31	−0.41	−0.60	−0.77	−0.50	−0.03	0.19	−0.13	−0.24	−0.22	0.05	−0.16
EX	0.92	0.87	0.80	0.74	0.87	0.85	0.85	0.74	0.66	0.83	0.81	0.66	0.84	0.78
T_1X	−0.14	−0.01	−0.63	−0.69	−0.74	−0.94	−0.71	−0.39	−0.47	−0.51	−0.40	−0.44	−0.08	−0.40
$E \cdot T_1X$	0.94	0.87	0.84	0.75	0.87	0.86	0.86	0.79	0.87	0.90	0.82	0.67	0.85	0.82
$T_1 \cdot EX$	0.52	0.03	0.71	0.75	0.75	0.94	0.74	0.55	0.82	0.75	0.43	0.45	0.24	0.52
$X \cdot T_1E$	0.94	0.87	0.90	0.85	0.91	0.96	0.91	0.83	0.90	0.93	0.84	0.73	0.85	0.85
$ET_1 \cdot X$	0.51	−0.02	0.42	0.21	0.16	0.16	0.27	0.42	0.76	0.63	0.16	0.11	0.23	0.29
$EX \cdot T_1$	0.94	0.87	0.82	0.69	0.80	0.59	0.81	0.79	0.87	0.90	0.81	0.65	0.85	0.80
$T_1X \cdot E$	−0.52	0.02	−0.67	−0.63	−0.57	−0.84	−0.62	−0.55	−0.81	−0.74	−0.36	−0.41	−0.24	−0.47

nated by 1954A in Table II. Simple, multiple, and partial correlation coefficients are listed in the table for each of these groups separately. In addition, the right-hand column gives a weighted average of the coefficients of the groups. This average has no precise theoretical significance and is merely a kind of over-all index of correlatedness. The last two rows of the heading give the minimum value a coefficient in any column may have and be significantly different from zero at the 99 or 95% confidence level, respectively.

The variables examined for correlation in addition to T_0 and T_1 were E, Y, and X, where

$E = E_1 - E_0$ for 1951 and 1953 crops, and E_1 for 1954 crop.

Y = skein strength of 22's carded yarn for medium staple cottons or 36's combed yarn for long staple cottons.

X = X-ray angle.

All possible simple coefficients of correlation were computed for the five variables taken two at a time. In addition all possible multiple and partial coefficients of correlation were computed taking three variables at a time where one of the variables was E. Table II is divided into six parts because there are six possible groups of three variables, one being E. In each part, the notation in the left-hand column designates the type of coefficient found on each row. For example, AB would represent the simple correlation coefficient between A and B. A multiple correlation coefficient would be represented by $A \cdot BC$ which would give the correlation between A and the two variables B and C. A partial correlation coefficient would be represented by $AB \cdot C$ which shows how A would be correlated with B if C were held constant.

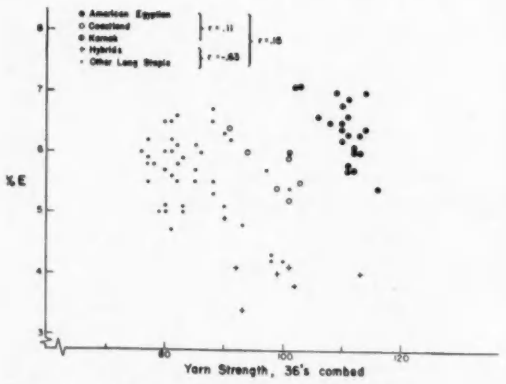

Fig. 1. Percent elongation of fiber bundles versus yarn skein strength for 78 long staple cottons of the 1953 crop.

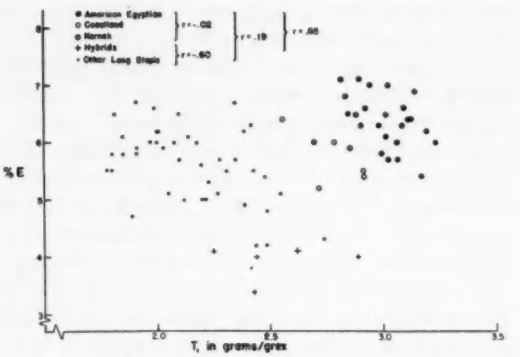

Fig. 2. Percent elongation of fiber bundles versus tenacity at $\frac{1}{8}$-in. gauge length for 78 long staple cottons of the 1953 crop.

A careful study of Table II fails to show any consistent relation between percent elongation and yarn strength. It will be noticed, for example, that the average difference between $Y \cdot ET_1$ and YT_1 is extremely small, indicating that Y would be predicted no better from knowing E and T_1 than from knowing T_1 alone. Similarly, the partial correlation coefficient $YT_1 \cdot E$ is generally no lower than YT_1. An exceptionally large value of EY does occur, however, for some of the long staple cottons. The reason behind this becomes apparent from an inspection of Figure 1, in which are plotted corresponding values of E and Y for all 78 long staple cottons of the 1953 crop. It is clear from the figure that the correlation coefficient between E and Y depends very strongly on the genetic group or groups which happen to be included in the analysis.

Since the correlation between Y and T_1 is so consistently high for all groups in the table, the relation between E and T_1 for the same cottons was also explored graphically. The results are displayed in Figure 2. Experience with other textile fibers such as flax and ramie might lead one to expect a pronounced negative correlation between tenacity and elongation. The cottons represented in Figure 2 exhibit very poor correlation as a whole ($r = 0.19$), although the long staples other than those classed with American Egyptians have a coefficient of -0.60. It is interesting to notice that if the hybrids happened to be included with the American Egyptian-type cottons, a positive coefficient of 0.65 would result. This group-

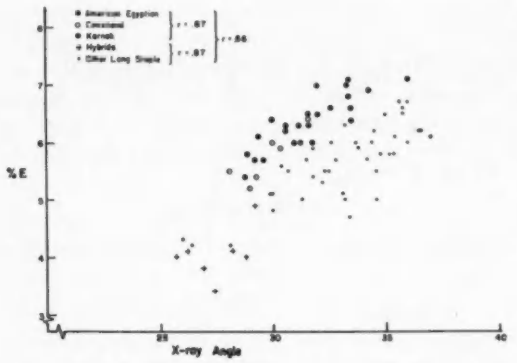

Fig. 3. Percent elongation of fiber bundles versus X-ray angles for 78 long staple cottons of the 1953 crop.

ing would be a reasonable one to choose since American Egyptians, Coastlands and Hybrids have all been selected for high strength at zero gauge length. The behavior of these cottons in Figure 2 could be accounted for by assuming that all are composed of high strength cellulose, but vary in intensity and distribution of weak spots along the fibers. Thus, the fibers with more pronounced weak spots would break before stretching very far. The influence of weak spot distribution is also seen in the fact that the ratio of T_1/T_0 is lower for the Hybrids (0.51) than for the American Egyptians (0.62). Values of T_0 are about the same for these two groups of cottons.

Correlation between elongation and X-ray angle is high for all groups in the table, but is generally higher for small groups than for combinations of them. To illustrate, in Figure 3 are plotted values of E and X for the same cottons presented in Figures 1 and 2. Again it will be noticed that correlation can be strongly influenced by the genetically related groups which happen to be included in a calculation.

It will be noticed in part D of Table II that the correlation between T_0 and T_1 is rather high for all groups except the 194 medium staple cottons from the 1954 crop. In Table III, the three simple coefficients which can be formed from these two variables and yarn strength are listed for both this group and the group of 25 long staple cottons selected from the same year's crop. These six coefficients illustrate an interesting point. The very high correlation between T_0 and T_1 in the long staple cottons makes it impossible to decide which of these two variables is chiefly responsible for yarn strength. The lower correlation between T_0 and T_1 in the medium staples, however, allows one to distinguish between their correlations with Y. In addition, as is seen in part C of Table II, YX is -0.04 for the medium staple group. It can be concluded, therefore, that for this group of 194 medium staple cottons, yarn strength would be very poorly predicted from either X-ray angle or bundle tenacity measured at zero gauge length, but it is highly correlated with tenacity measured at $\frac{1}{8}$-in. gauge length.

TABLE III. Correlation Coefficients between Values of T_0, T_1 and Y for Two Groups of Cottons Selected from the 1954 Annual Varietal and Environmental Study

	Long staple	Medium staple
No. of samples	25	194
T_0T_1	0.96	0.44
YT_0	0.95	0.38
YT_1	0.96	0.86

A simple correlation coefficient of 0.70 (different from zero at the 99% confidence level) was computed between Stelometer E and percent single end 22's yarn elongation as measured by Brown [1] on 47 of the cottons used in this test. Simple correlation coefficients were also computed between Stelometer E and various properties measured by Wakeham [12] on a few of the same cottons. The properties and corresponding coefficients are listed in Table IV.

TABLE IV. Simple Correlations between Stelometer Elongation and Various Properties Measured by Wakeham on Cottons Selected from the 1951 Annual Varietal and Environmental Study

	r	No. of samples
E vs. single fiber elongation	0.92	16
E vs. flat bundle elongation at 5 mm. gauge	0.93	21
E vs. single end yarn elongation at 2-in. gauge	0.91	21
E vs. single end yarn elongation at 20-in. gauge	0.90	21

Ten cottons covering a wide range of tenacity and elongation were selected to be tested on the Instron by Southern Regional Research Laboratory. The cottons were run twice on the Stelometer, one run preceding, and one following the Instron tests. They were run twice on the Instron also, each run being made with a different crosshead speed. To minimize variability due to sample preparation, the same operator prepared samples for both instruments. Correlation coefficients between instruments and between runs are shown in Table V. From the extremely high correlation between instruments, it is evident

TABLE V. Correlation Coefficients between Stelometer and Instron Data

	T_1	T_0	E_1	E_0
Stelometer vs. Instron	0.997	0.993	0.985	0.855
Instron 1st speed vs. 2d speed	0.992	0.981	0.968	0.761
Stelometer 1st run vs. 2d run	0.995	0.991	0.994	0.929

that both are responding in about the same way to the same properties of the cotton.

Conclusions

An extensive analysis of correlations among Stelometer readings and other available measured properties for a large number of cottons has been made. The only yarn property found to be definitely correlated with fiber bundle elongation was yarn elongation. Fiber bundle elongation was also correlated with X-ray angle and less strongly with tenacity measured at zero gauge length. Skein strength was highly correlated with tenacity measured at $\frac{1}{8}$-in. gauge length. Stelometer values of tenacity and elongation were very highly correlated with Instron values on the same cottons. The best procedure at present for getting percent elongation with the Stelometer is to multiply elongation scale reading at $\frac{1}{8}$-gauge length break by 0.80.

The properties compared with bundle elongation in this study, being limited to those available, do not seem to have included any except yarn elongation which are strongly dependent on bundle elongation. Since elongation is closely connected with energy required to break fibers, it would be interesting to compare it with yarn and fabric properties which are dependent upon energy absorption, such as abrasion resistance and tear strength.

Acknowledgments

The authors wish to express their indebtedness to Field Crops Research Branch of the Agricultural Research Service of the U.S.D.A. for all of the cotton samples studied and for the unpublished X-ray angle data on cottons of the 1951 and 1953 crops. They are also most grateful to Drs. Brown and Wakeham for the opportunity of examining their data on yarn elongation before publication. They appreciate the suggestions and assistance of James N. Grant, who served as representative of Southern Regional Research Laboratory in supervising the contract under which this work was done, and his aid and that of the Southern Regional Research Laboratory staff in obtaining the Instron data used. Special thanks are due Reba Lawson for a large part of the data and all the calculations in this report.

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Spinning Coarse Yarns from Drawing Sliver

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THERE is nothing new in the art of spinning yarns from sliver. This idea goes back well over 100 years. The records show that during 1836 a man named Day patented a continuous process which amounted to spinning direct from sliver. Since that time many one-process systems have been developed which are successfully producing quality yarns.

The industry is familiar with the method being used in spinning fine yarns where a small can of drawing sliver is placed directly on the frame, replacing the conventional bobbin of roving. At the recent Brussels Show, one-sided frames spinning direct from sliver were exhibited by Zinser and Pfenningsberg.

Most of the study and developments of spinning direct from drawing sliver have been confined to the spinning of fine yarns in counts finer than 12's with very little thought given to a practical arrangement for spinning coarse yarns in counts 10's and coarser. To spin coarse yarns economically requires the supply cans to be as large as possible to give maximum runs between creelings. The use of cans in a size 14 × 36 or larger as a supply does create a problem of developing the most practical arrangement of the creel for best operation of the frame. There is also the problem of properly placing cans at the frame from the standpoint of floor space requirements.

The Linen Thread Co., being spinners of coarse yarns for processing into threads and twines, are constantly in search of practical, efficient, and economical processes for producing our coarse yarn requirements. This led us to the study of a frame developed by Saco-Lowell. After research and extensive experimenting, one unit was purchased consisting of a full-length 200 spindle Gwaltney Frame equipped to produce a range of yarns up to 10's direct from drawing sliver. We have been experimenting with this frame for the past few months with satisfactory results in quality of yarns produced. The creel arrangement and placing of supply cans, however, calls for further study to effect an ideal and practical setup for full scale operation.

A cross-section view of the spinning frame is seen in Figure 1. It shows schematically the drafting elements, the method of feeding the sliver, and the arrangement of the supply cans. The frame is a 4½-in. gauge with 3½-in. rings and 12¼-in. traverse. In this illustration the supply cans are shown placed on the floor on both sides of the frame with a sufficient working alley between cans and frame.

Figure 2 is an end view of the frame, showing supply cans in two different arrangements. On the left, all cans are directly on the floor and on the right, one can is on the floor with the other placed on the rack above to conserve floor space. Using this method, instead of having both cans on the floor, 25 in. of floor space is picked up. Floor space is a definite problem and one that calls for careful study when planning an installation. With all cans placed directly on the floor, the over-all width per frame including the cans is 135½ in., allowing 27½ in. working alleys. With cans placed one above the other, the over-all width is reduced to 110½ in.

This setup is the latest change made in an effort to arrive at a practical arrangement for the creel, the travelling cleaner and the supply cans. The installation of the travelling cleaner has presented a problem and this work is being continued with the cooperation of the Parks Cramer Co. Originally the track for the cleaner was approximately 5 ft. from the floor. It was necessary to raise the track

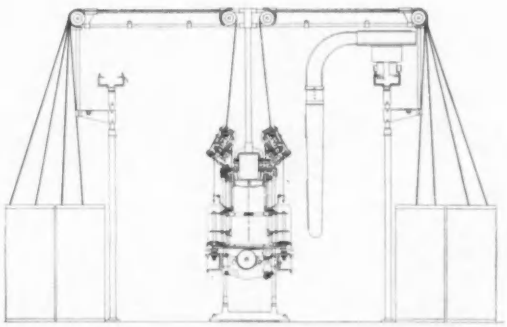


Fig. 1. Cross-section view of Gwaltney spinning frame.

to a position 6 ft. from the floor to allow proper clearance for a person of average height to walk under. This necessitated raising the sliver lifting rolls to a position approximately 8 ft. from the floor. It may be questioned whether this creel arrangement, with the lifting rolls being 8 ft. from the floor, is practical from an operating standpoint. I will agree it calls for further study. However, we have found from experience, it will run with practically no trouble due to sliver breaking back in the creel. To creel the frame from scratch is somewhat of a problem and is costly. In creeling, the same method is followed as that used on a slubber.

Figure 3 is a close-up view of the drafting element,

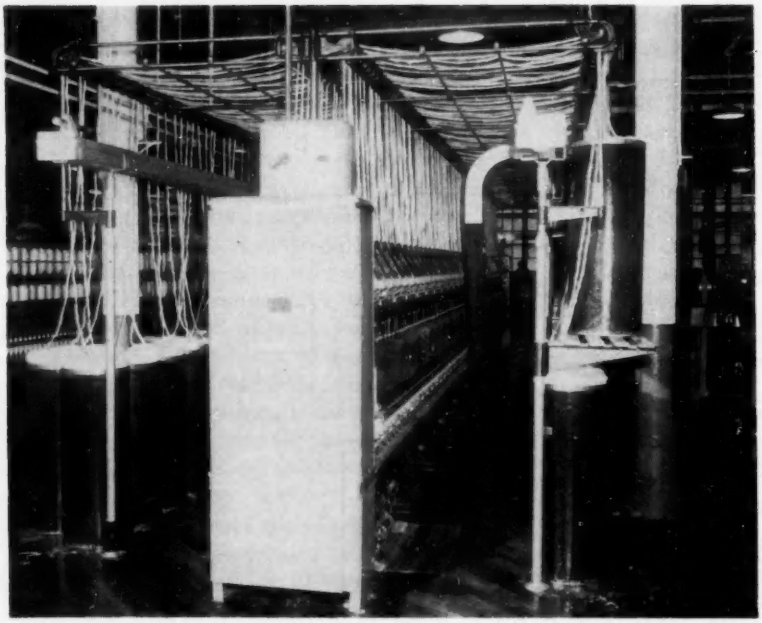


Fig. 2. End view of installation of Gwaltney frame equipped to spin direct from drawing sliver, installed at the Linen Thread Company. Shows one arrangement of cans. Left, with both cans on floor. Right, one can placed above the other.

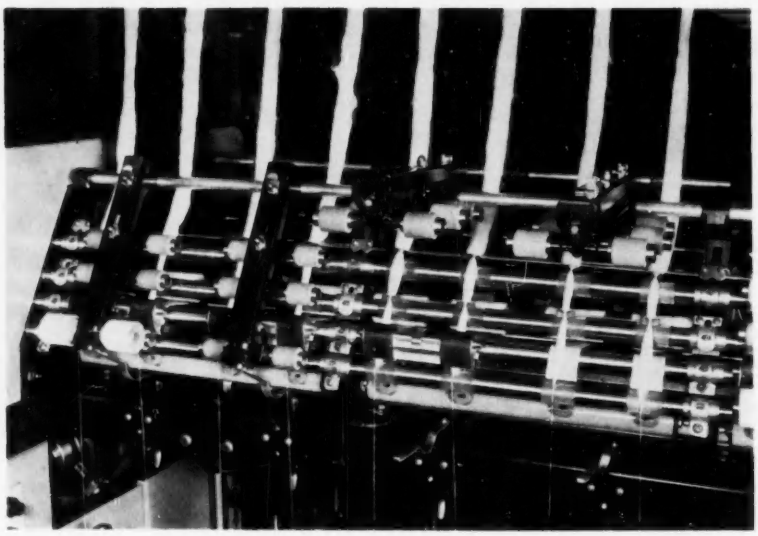


Fig. 3. Close-up of drafting element. Top rolls in operating position at left. Rolls in raised position at right.

showing the top rolls in operating position on the left and on the right, the rolls in raised position. This is a three-zone element with Duo-Roth in the front zone where the major portion of the draft occurs. The draft will run approximately 1½ in the back zone and 2½ in the intermediate or middle zone. Total drafts are generally in the range of 30 to 60, although a draft of better than 100 has been processed satisfactorily. In our experiments, sliver weights of 50 to 55 grains/yd. were used in spinning yarns ranging from 4's to 10's.

Figure 4 is the head end roll gearing as well as the chain drive which operates the sliver lifting rolls. Change gears are provided to regulate the speed of the lifting rolls.

The sliver coming from the supply can is shown in Figure 5. Note there are two ends individually coiled in each can. The can presently being used is 14 × 36 and when processing 100% cotton, a full can will contain approximately 20 lb., slightly less when processing 100% waste, or waste and cotton blends. When spinning 8's warp yarn, a full can will last approximately 80 hr. compared with only approximately 25 hr. when using 12 × 6½ roving package in the creel. With the supply can running 80 hr. or 10 shifts in the creel when spinning 8's yarn, the creel can be staggered on a 200-spindle frame with 100 cans in the creel so that it would be necessary to creel only 10 cans per shift.

Figure 6 shows the twin strand draw frame developed for use in spinning from sliver. Cover is removed from one delivery to demonstrate the two tube gears used in producing separate coiling of the two individual ends per can. To prevent overlapping of the coils and subsequent tangling, as sliver is removed from the can, the cans rotate ½ revolution clockwise and then ½ revolution counterclockwise alternately throughout the filling of the can.

Let us consider for a moment the quality of yarn produced. In all cases, yarns spun from sliver show an improvement in break as compared to yarn spun from identical stock on 3-roll conventional spinning. In Table I and Figure 7 are shown tests results of yarn from three different stocks; namely, blend of 75% waste—25% cotton; 75% cotton—25% waste; and 100% cotton. The yarn spun from sliver, is

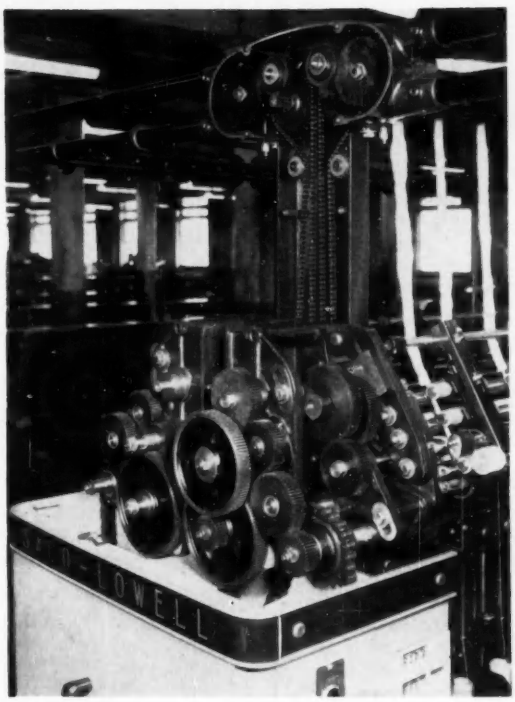


Fig. 4. Head roll gearing and chain drive.

TABLE I. Break Factors for 8's Yarns

	Break factor	Increase
75% Waste—25% cotton		
8's Yarn—standard	1258	
8's Yarn—can-spin	1492	18.6%
75% Cotton—25% waste		
8's Yarn—standard	1410	
8's Yarn—can-spin	1627	15.4%
100% Cotton		
8's Yarn—standard	1975	
8's Yarn—can-spin	2242	13.5%

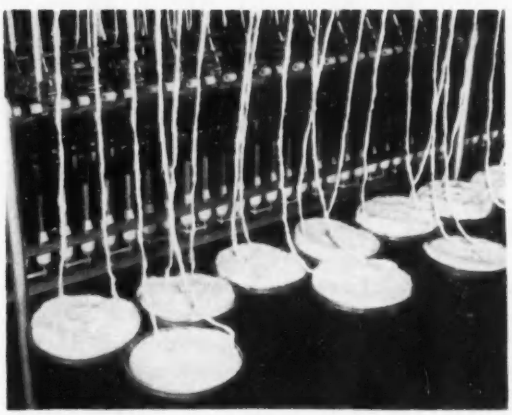


Fig. 5. Sliver being drawn from supply cans.

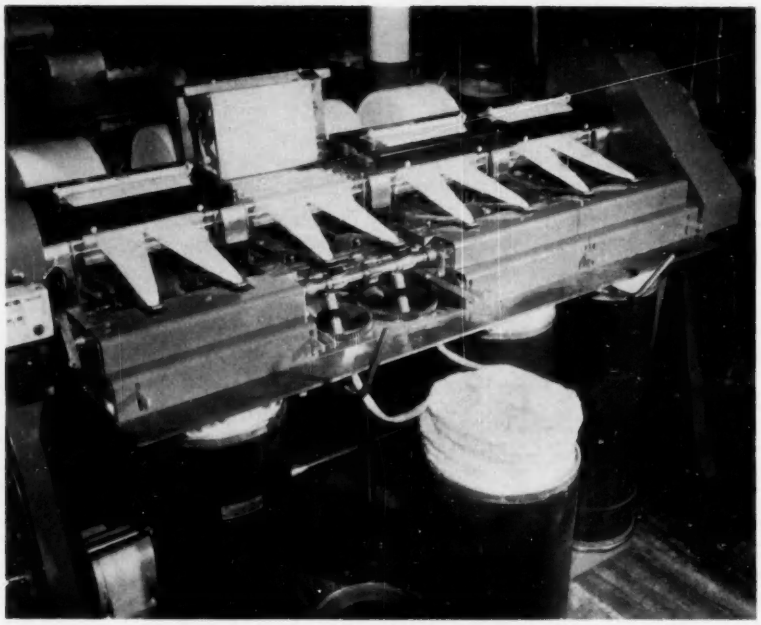


Fig. 6. Twin-strand draw frame developed for spinning direct from sliver.

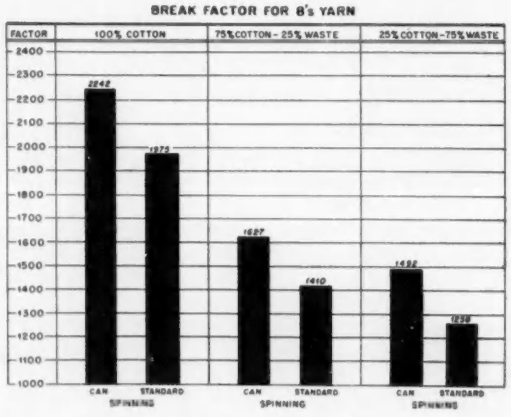


Fig. 7. Break factor for 8's yarn.

referred to as "can-spin," and the yarn from 3-roll conventional spinning as "standard." Table II shows results of a laboratory test on 9.50's yarn.

We have been operating the frame at spindle speeds of 4000 to 6600 r.p.m. on a range of yarn sizes from 4's to 10's in various qualities and twists. The frame has been run equipped with 3½-in. rings at speeds comparable with those considered standard

TABLE II. Laboratory Test Results of Comparative Test on 9.50's Yarn

	Can-spin	Standard
Break factor	2250	2010
Single strand break	930 g.	808 g.
Uster—maximum variation	74.8%	93.4%
Uster—integration variation	15.2%	18.4%

for the yarns processed. With the elimination of the roving operation, one of the major sources of yarn defects, the use of modern drawing, and good performance on the spinning, the yarn imperfections are held to a minimum. The improvement in quality of yarn, plus the larger package, will show substantial reduction in winding cost. There is also a possibility of using this larger package directly on a twister creel, thereby eliminating the winding entirely.

No definite conclusions have been drawn as to the operator assignments. However, with the elimination of the roving operation and increased assignments in the spinning, there are substantial savings in direct labor.

A full bobbin of yarn will average a net weight of 19½ oz. which means each doff on a 200 spindle frame is equal to one-half bale of cotton.

Super High Draft Spinning: Sliver to Yarn

Edward S. Rudnick[1]

Introduction

It has long been a dream of textile manufacturers throughout the world to spin cotton yarns directly from sliver. Research institutions in most of the major textile-producing countries as well as various machinery manufacturers have attempted this from time to time. In most cases, the developments were discarded because the yarn quality was poor or because the process was not practical or economical. However, since World War II, there has been a revival in this thinking and the first real practical development of this sliver to yarn spinning has come out of Japan. Specifically, the development is called Super High Draft spinning and was perfected by the O-M Spinning Machine Company of Osaka, Japan, about seven years ago. It consists essentially of two Casablancas systems in tandem.

From the theoretical point of view, the spinning of yarns directly from drawing sliver represents substantial advantages other than the obvious savings in the elimination of all roving frames, (*i.e.*, floor space, power, maintenance, depreciation, work-in-process inventory, etc.).

From the quality point of view, finisher drawing sliver represents the most even strand (for short- and long-term variation) in the mill. The roving process not only creates about twice the short-term unevenness, but also represents a reversal in the direction of drafting. In fact, numerous recent studies have shown that when the drafting takes place in the *same* direction, there is less possibility of introducing unevenness.

Furthermore, roving represents such a degree of attenuation that twist must be inserted to hold the strand together. This twist, normally inserted by flyers, is a source of considerable trouble. The fiber parallelization of the drawing sliver is disturbed. Also, the twist in the roving must be taken into account with break-drafts on the next operations. In fact, we all recognize the difficulties encountered when the roving twist is too high or too low.

Furthermore, the revolving flyer on a roving frame is a source of as much as 2% invisible fly waste in the card room. Thus, the roving frame can be considered as a "necessary evil" in a cotton mill and a source of numerous yarn difficulties like dirty piece-ups, gouts, bunches, break-backs in the spinning creel, cockled yarn, etc.

Therefore, if we can start with finisher drawing sliver and maintain the relative fiber orientation throughout the spinning drafting system, we ought to have a better yarn than when roving frames are used as intermediary processes. This has been achieved on the OM-S Super High Draft frame.

The OM Super High Draft Frame

At first the system was applied to more conventional types of spinning wherein the Super High Draft elements were used for spinning yarns from coarse rovings with approximate drafts of 80 to 120. These frames, designated OM-K, are still being manufactured. In fact, nearly 500,000 spindles are now in use. (I was recently in a print cloth mill in Japan where the 40's were spun from 0.5 hank roving and the 30's from 0.4 hank.)

Shortly after the introduction of the OM-K, the drafting elements were refined and the frame redesigned to accommodate cans of drawing sliver. These frames were designated OM-S Super High Draft and are now capable of practical drafts as high as 600; in fact, experimental drafts in excess of 700 have been achieved. For all practical purposes, this means that *all* cotton yarns can be spun directly from sliver on the OM-S frame. At the present time, over 500,000 spindles of OM-S are in operation in Japan, India, Pakistan, Brazil, Egypt, and the United States. Currently O-M is building these frames at the rate of 40,000 spindles per month. Figure 1 shows one such installation of OM-S frames.

Figure 2 gives a general over-all picture of an OM-S Super High Draft frame. Note that there is no buffet on this new-pattern machine, as the motor is under the frame. The topmost portion of the frame is the moving sliver guide roll and stands a little over 5 ft. from the floor. Thus, a relatively short overseer can literally oversee the spinning room from any position in the room.

[1] U. S. and Canadian sales representative for O-M Spinning Machine Manufacturing Co., Ltd. (Osaka, Japan). P. O. Box 244, New Bedford, Mass.

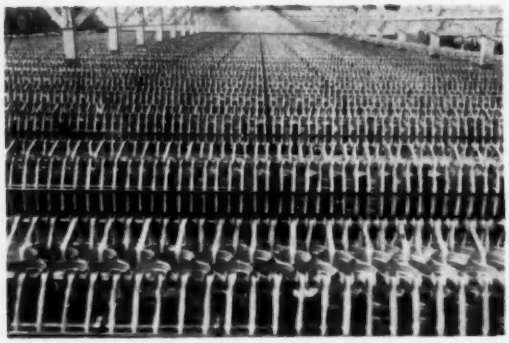


Fig. 1. An installation of OM-S, super draft spinning frames, in a Japanese mill.

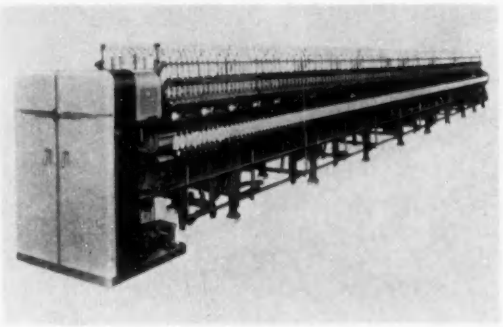


Fig. 2. The OM-S, super high draft frame.

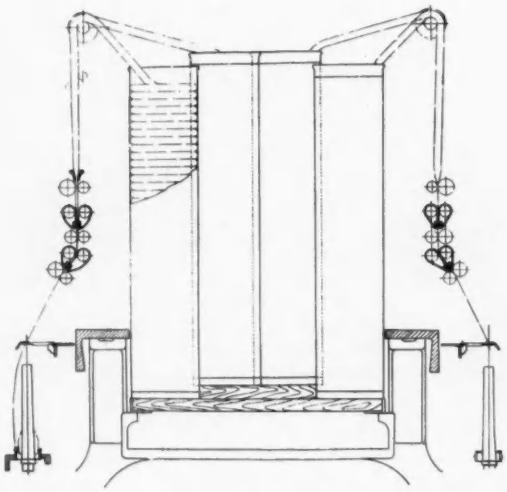


Fig. 3. Schematic sketch of cross section of OM-S frame showing arrangement of rollers.

In Figure 3 we see the cross section of this frame and the arrangement of the rollers. The frame is two-sided, and the width of the frame varies with the spindle gauge and diameter of can. For instance, a frame with a 3-in. gauge utilizes a 5⅜-in. can and has an over-all width of only 37 in., or 2 in. narrower than a conventional frame.

One of the patented features of this machine is the arrangement of the drafting rolls. Figures 4 through 6 show these in more detail, but note that the first three rolls are in a vertical position and the next two are at a 60° angle. This arrangement keeps the frame width at a minimum while still allowing the twist of the yarn to run directly into the nip of the two front rolls and also make for easy piecing-up.

A close-up of the drafting roll cradles is shown in Figure 4. The cradles are hooked, by means of a clamp, to projecting ears on the bottom cradle. Thus by releasing this clamp the cradle can be lifted out. During shutdowns, releasing the clamp relieves the roller pressure and the cradle can be left hanging. To reapply the pressure, the clamp is just snapped down with the finger tips.

In Figure 5, both the front and back top cradles have been removed exposing the bottom cradles. Now the drafting arrangement can be seen clearly. The first three rolls in the vertical position correspond to a Casablancas double apron roving frame, while the front two rolls, in conjunction with the front roll of the roving section, correspond to a Casablancas spinning frame. Drafts of up to about 20 are achieved in the roving section and about 30 in the spinning section, for an over-all draft of up to 600.

The secret of success of this drafting system lies in

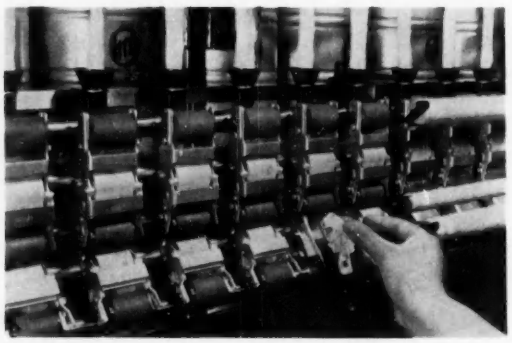


Fig. 4. Close-up view of drafting roll cradles on OM-S frame.

the control of all fibers, especially the short ones, in the draft zones. We all know that drafting waves are ordinarily caused by the short fibers being grabbed too early by the front roll or held back too long by the back rolls. On the OM-S frame, an extreme degree of control is achieved both by the design of the cradles and by means of so-called collectors between each pair of rollers or aprons. These collectors (or condensors) are supported by wires; their bottom surfaces have the same curvature as the respective top and bottom rollers so that they actually ride on these rollers. At the same time, they are shaped to fold in the edge fibers and maintain the fiber bundles in ideal rectangular cross sections of smaller and smaller areas at each pair of rollers. In fact, the Japanese have made quite a study of the ideal ratio of the length to width of this cross section to give maximum control of the edge fibers while still not losing control of the inner fibers. The top trumpet has this same cross section and is mounted on a traversing guide bar. For fine yarns, the second collectors are similarly mounted to a separately adjusted traversing bar.

Thus, these collectors literally feed the fibers directly from the nip of one pair of rollers into the nip of the next pair. So excellent is the fiber control that several mills in Japan actually blend a certain percentage of short fiber in with their longer mixes without sacrificing on evenness. Another example of this fiber control is that about 20% of the half million OM-S spindles are running on synthetics and blends up to 3 in. in staple length with both the short and long fibers being in good control. In fact, on the sample frame at the New Bedford Institute of Textiles and Technology, one side is set for $1\frac{1}{2}$-in. ratch distances; yet, it has been possible to run everything from $\frac{7}{8}$-in. cotton to $1\frac{9}{16}$-in. Dacron without bothering to change the control settings, and very satisfactory results have been achieved as to evenness, as will be shown later. A cross section of the roller arrangement is illustrated in Figure 6.

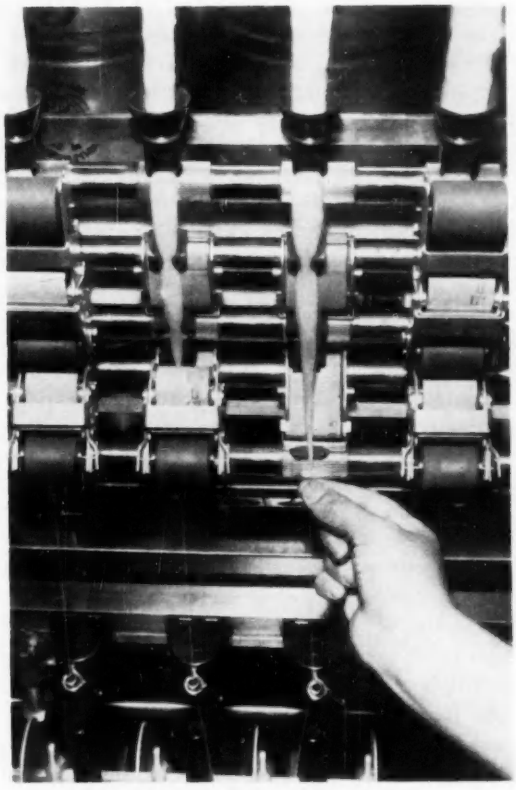
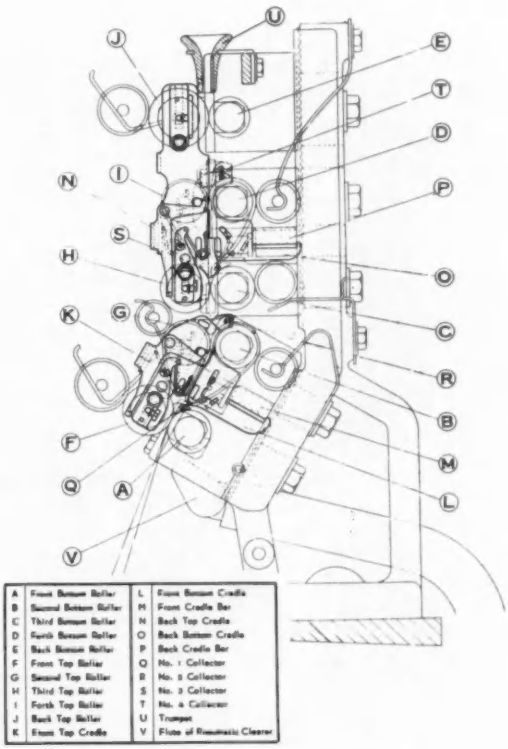


Fig. 5. Front and back top cradles removed.



A	Front Bottom Roller	L	Front Bottom Cradle
B	Second Bottom Roller	M	Front Cradle Bar
C	Third Bottom Roller	N	Back Top Cradle
D	Forth Bottom Roller	O	Back Bottom Cradle
E	Back Bottom Roller	P	Back Cradle Bar
F	Front Top Roller	Q	No. 1 Collector
G	Second Top Roller	R	No. 2 Collector
H	Third Top Roller	S	No. 3 Collector
I	Forth Top Roller	T	No. 4 Collector
J	Back Top Roller	U	Trumpet
K	Front Top Cradle	V	Plate of Pneumatic Cleaner

Fig. 6. Cross section of roller arrangement.

Another reason for the excellent results on this OM-S system is that in the roving section the drafting takes place at an extremely slow rate. For instance, with a 150 r.p.m. front roll speed and a draft of 300, as might be the case in spinning a 40's, the back roll speed would be $\frac{1}{2}$ turn/min. Incidentally, at this rate, it would take almost a week of three-shift operation to empty the sliver can.

Figure 7 shows the cradles disassembled. The bottom cradles bolt to individual cradle bars, which in turn are attached to the roller stands. Since there is no contact between the moving rollers and these bottom cradles, there is no friction or wear and considerable power is saved. In fact, a 400 spindle OM-S frame normally running at a 10,000 r.p.m. spindle speed or higher requires only a 10 h.p. motor. The top cradles clamp onto the bottom cradles, the roller pressure being applied by means of Swedish piano-wire springs on either side of the cradle. These springs are made to very close tolerances and are 100% tested before and after assembly. They are made to any specified roller pressure and are readily interchangeable.

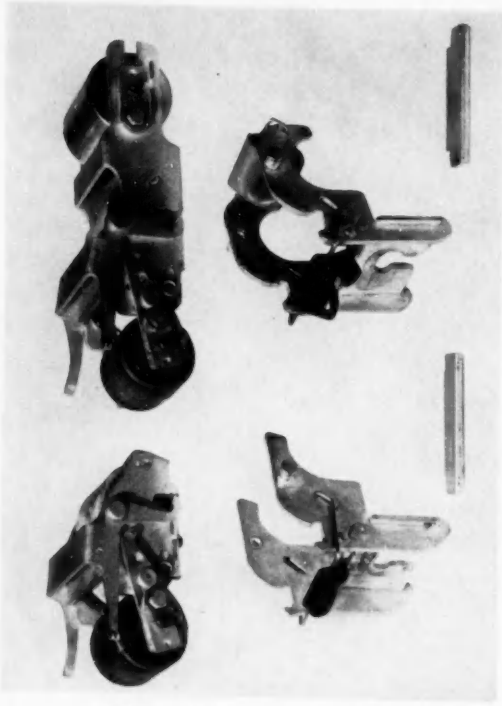


Fig. 7. Cradles disassembled.

The clamp acts as a fulcrum so that a pair of springs on either side of the cradle controls the pressure of both the back roll and the front roll. In fact, the back cradle is designed so that the distances from the fulcrum to the back roller are somewhat greater than the distances to the front roller, giving the back roll slightly less pressure.

This means of application of roller pressure gives equal pressure on both sides of the roll—a virtual impossibility with the conventional saddle and cap bar-type cradle. Furthermore, each spindle is entirely independent of each adjacent spindle so that a lap-up on one roll cannot possibly influence the next one. As a matter of fact, with the plate-type separators, antiballoon rings for large package spinning, pneumatic clearers, and this cradle arrangement; the number of ends-down caused by adjacent ends-down is definitely minimized. There are similar piano-wire springs (not shown) on the insides of the cradles which support the apron rolls and apply the pressure of the top aprons against the bottom ones.

Another excellent feature of these patented cradles is the method by which the top rolls are supported and released. The arbors are supported by so-called stoppers whose length determine the roller settings of the cradles. These stoppers pivot to allow the rollers to be readily removed. By interchanging these stoppers, the roller settings of the cradles can be changed, while the settings of the fluted rollers are changed by set screws on the roller stands. (As mentioned above, such changes in roller settings are seldom necessary.) The bearing surfaces of the rubber rollers and steel apron rolls are made either with an impregnated Bakelite oilless construction or with ball bearings.

Essentially, the parts below the roller beam are quite conventional, although numerous features have been incorporated, such as roller-bearing spindles, adjustable lappets and pigtails, clutch to disengage ring rail motion, one-shot lubrication system for all head-end bearings, doffing boxes on doffing rails, automatic yardage stop motion, gear cover safety switches, and a handle for automatically lifting all lappets during doffing. Thus, the OM-S Super High Draft elements can also be used for changing over existing frames.

As for filling these small cans for the spinning frames, O-M has developed a special automatic can filling mechanism for draw frames, as illustrated in Figure 8. In place of one large can, there are four

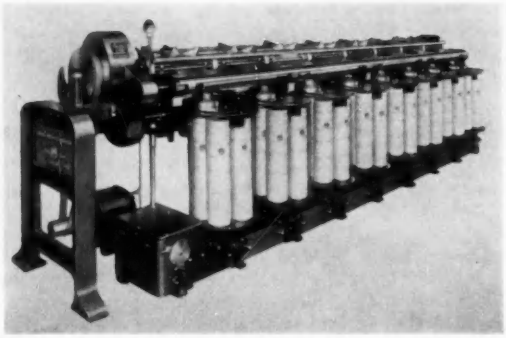


Fig. 8. Can-filling mechanism for finisher drawing frames.

small ones, the coiling mechanism filling one can at a time. A yardage indexing head is used to predetermine the exact yardage delivered into each can. As soon as this yardage has been coiled into the respective cans, all of the turn tables automatically rotate 90° while a knife edge just below the coiler table rotates through 360°, cutting the sliver and throwing the tail to the outside of the can. Thus, no production is lost in doffing these draw frames, and two or three cans can be doffed simultaneously from each delivery at the convenience of the drawing tender or doffer.

TABLE I. OM-S Operating Data in Japanese Mills

	Mill A	Mill B	Mill C
Total spindles, OM-S	30,000	50,000	50,000
Major yarn counts (for data collection)	30's, 40's	40's	40's
Ring size	1¾ in.	1⅞ in.	1⅞ in.
Spindles/frame	420	400	420
Staple lengths	1 1/32 in. 1 1/16 in.	1 1/16 in.	1½ in. 2½ in. rayon
Spindle speed	10,400 r.p.m.	9600 r.p.m.	11,000 r.p.m.
Front roll speed (⅞ in.)	152 r.p.m.	137 r.p.m.	
Creeling practice	Individually	By sections	By spinners
Spindles/spinner	3260	3200	2940
Spindles/doffer (team doffing)	3260	3600	3790
Spindles/creeler	10,080	5200	0
Ends-down/M spindle-hr.	22	25	18

The drawing frame is thus a combination draw frame and "packaging machine" for the spinning operation. Since each can has the same amount of yardage in it, the spinning frames are usually gang-creeled by sections. In fact, the yardage in the drawing can is predetermined to be a multiple of the number of hanks per spinning bobbin divided by the spinning draft, so that each section can be creeled just prior to the doff. This means that any bad piece-ups or broken ends occur on the bottom layers of the next bobbins.

Operating and Test Data

During the past several months, I have had a dual opportunity to study these machines, from the quality point of view, on the New Bedford sample frame and, from the production point of view, in several mills in Japan. Table I summarizes my observations in three of these Japanese mills. It might be mentioned that it is difficult to make a direct comparison between workloads in Japan and those in the U.S. (I had the general impression that in all Japanese mills the percentage of time each worker spends on cleaning and machine maintenance is much greater than that spent in the United States.) Thus, these work loads, even though substantial on full-scale operations, would probably be higher in the U.S. Normal American practice would be to relieve the spinners of all creeling, thereby greatly increasing their work loads, while either letting the doffers do the creeling (with a diminished work load) or creating a new job of "creeler," as in Mills A and B.

From the quality point of view, Table II summarizes the average yarn strengths on the OM-S frame compared with the standards of the Japanese Cotton Spinning Association. In actual installations, the OM-S frames usually yield 5 to 10% higher break factors than that of conventional frames. In fact, many of the independent weavers and knitters in Japan are now specifying "OM-S spun yarns."

TABLE II. Comparison of Yarn Strengths

Yarn count	20's	30's	40's	60's	80's	100's	120's
Standard strength of Japan Cotton Spinning Association (lb.)	68	48	37	28	25	20	16
Average strength of Japan Spinners' Inspection Foundation (lb.)	92	61	45.7	35	31		
Tenacity of yarn spun by the OM-S type ring frame (lb.)	98	70	51	37.5	33.5	24	19

TABLE III. OM-S Spinning Tests versus Control Samples

Count		Factor	Av. size	Skein break (lb.)	Appearance	Single strand (lb.)	Uster evenness (%)
19's C	OM-S	2786	19.0	146.2	B+		
	Reg.	2772	19.5	127.5	B		
22's K	OM-S	1962	21.8	90.0	B		
	Reg.	1882	21.4	98.0	B		
30's K	OM-S	2489	30.4	82.0		0.65	
	Reg.	2355	31.2	75.5		0.58	
31's K	OM-S	2366	32.2	73.7	B+		
	Reg.	1950	31.0	62.9	B		
33's K	OM-S	2106	33.2	62.2	B+		107 (Av. Max.)
	Reg.	1949	33.3	58.5	B+		112
40's K	OM-S	2010	37.7	53.3	B		
	Reg.	1960	40.9	48.0	B		
40's K	OM-S	2150	41.3	52.0		0.46	
	Reg.	1973	40.0	49.5		0.43	
40's C	OM-S	2413	39.3	61.4		0.57	17.0 (Int.)
	Reg.	2273	39.5	57.3		0.50	17.2
45's C	OM-S	3275	45.5	72.5	A−		
	Reg.	3082	45.8	67.3	A−		
45's C	OM-S	2430	44.9	54.1	A−		
	Reg.	2290	45.4	50.4	B+		
50's C	OM-S	2219	51.0	43.5		0.43	17.9 (Int.)
	Reg.	2225	49.4	45.2		0.41	20.5
60's C	OM-S	3219	56.0	57.5	A		
	Reg.	3162	58.5	54.0	A		
78's C	OM-S	2661	75.1	35.4	A		105 (Av. Max.)
	Reg.	2467	77.7	31.7	A		116
80's C	OM-S	2339	80.6	30.0	A		
	Reg.	2418	81.5	28.7	A−		

As for my observations of OM-S quality at New Bedford, we have spun about forty different yarn counts for over a dozen different American and Canadian companies, ranging from 7.5's to 105's. While I do not have comparisons for all of these, Table III summarizes many of them and indicates that the OM-S spun yarns are either equal or superior to conventional spun yarns from the same stock.

Conclusion

In summarizing, I would like to say that I personally feel there is a definite future for sliver-to-yarn spinning, whether made in Japan, Germany, the U.S., or even Russia. Apparently, the Japanese have a head start on the rest and are not standing still; they are continuing to improve and refine these machines.

To reiterate, the roving process, as such, in a cotton mill has been a "necessary evil"—a source of many difficulties, and much dollar expenditure. When a machine is capable of combining several processes together while at the same time producing superior results, then it is only logical that it should eventually become generally accepted.

Book Reviews

Chemistry and Chemical Technology of Cotton. Edited by Kyle Ward, Jr. Appleton, Wisconsin, The Institute of Paper Chemistry: New York, Interscience Publishers, Inc., 1955. 801 pages. Price, $20.

Reviewed by George S. Buck, Jr., Technical Director, National Cotton Council of America, Washington, D. C.

The very attempt to describe in a single volume the enormously complex chemical technology of cotton would seem a monumental task. That Kyle Ward has succeeded in covering so much of the field is a tribute to him and the authors of the 14 chapters of this tremendous new work on cotton. *Chemistry and Chemical Technology of Cotton* will be a necessity for the serious cotton researcher and a valuable reference and information source for technologists in the cotton manufacturing and finishing industries, textile chemical concerns, and even for those who have only a general interest in the textile industry.

Volumes have been written on most of the subjects which are treated in chapter form in the book. The references alone, appended to most sections or appearing as footnotes, testify to the tremendous volume of work which has been reviewed and condensed and at the same time provide the specialist with additional resources. But Ward's most valuable contribution, perhaps, is in bringing together for the first time a rather complete and certainly well-organized story of the relationship between cotton and chemistry.

Several of the chapters are authored by Dr. Ward's former colleagues at the Southern Regional Research Laboratory. Guthrie and Conrad open the book with able discussions of the chemistry of lint cotton, in which Guthrie covers its composition and Conrad the chemical properties of cotton cellulose. In the light of the important future which many have predicted for chemically modified cottons, the limited space Conrad devotes to this aspect of cotton chemistry may be disappointing. Some additional chemical finishes, however, are dealt with in later chapters. Sizing and bleaching are rather thoroughly covered by La Piana and Valko, respectively. These two chapters point up the book's unusual (but useful) combination of the practical with the fundamental, a feature of the entire work. This general method of presentation makes the book easily readable without sacrificing its basic thoroughness.

Dyeing, by R. E. Rupp, and printing and related processes, by A. E. Hirst, are covered in considerable detail, particularly the latter subject. These two chapters will be especially valuable to students. The researcher, however, may deplore the fact that these chapters are not accompanied by literature references. Mercerization and water-resistant treatments are capably discussed by two more of Dr. Ward's former associates at the New Orleans Laboratory, C. F. Goldthwait on the former subject and H. A. Schuyten on the latter. Schuyten's chapter seems, to this reviewer, to be particularly well done. It should be of considerable value to anyone interested in water-repellent and water-resistant treatments for cotton.

The chapter on fire resistance by Church and Coppick is disappointing in its brevity and the fact that some of the treatments discussed are obsolete, while several of the newer finishes are not considered. However, the background which is presented will serve as a useful start for the would-be specialist in fire retardancy. In fairness to the authors, it must be acknowledged that current studies make the status of this field so fluid that an up-to-the-minute report may have been impractical.

Greathouse and Wessel review mildew-resistant treatments effectively and usefully, and D. H. Powers covers the important field of resin treatments for cotton. This latter subject has become one of great commercial importance for the cotton and textile industries, and thus Chapter X may be unusually valuable to technologists in the cotton, chemical, and finishing industries. Unfortunately the following chapter on the treatment of cotton for the rubber industry, while excellently presented by Lessig, Wilson, and Hebden, applies to a field in which cotton is currently less important than it was a few years ago.

Dr. Ruby K. Worner of the Southern Regional Research Laboratory ably presents a cross-section of the testing and evaluation of cotton textile products, and the laundering of cotton fabrics is thoroughly treated by J. Fred Oesterling. At first glance, many textile men may regard the attention devoted to laundering as somewhat more detailed

than necessary. However, with the increasing importance of textiles which have characteristics of easy washing and, particularly, the wash-and-wear fabrics, the extensive treatment of laundering may be completely justified.

As the final chapter in the book, chemical changes in cotton fabrics during processing and use are covered by J. D. Dean, former head of the Chemical Processing Division of the Southern Regional Research Laboratory. A glossary, author index, and subject index complete the volume.

Instruments for Measurement and Control. Warner G. Holzbock, New York, Reinhold Publishing Corp., 1955. 416 pages. Price $10.00.

Reviewed by Hillary Robinette, Jr., President, Robinette Research Laboratories, Inc., Ardmore, Pa.

With the emphasis on automation and instrumentation in practically every process industry, the demand for instrumentation becomes paramount. Anyone concerned with instrumentation and control will find author Holzbock's book of great value as a source of up-to-date useful information.

The volume, written in popular language, describes and evaluates the various instruments for measuring temperature, moisture, pressure, flow, viscosity, uniformity, etc. The mechanics of the instruments are considered as well as the adjunctive devices, such as pumps, transformers, motors, and valves.

The first nine chapters of the volume deal with the measurement and control of physical properties of materials. As an example, the first chapter relates to the measurement and control of temperature. The various devices used for measuring temperatures, such as millivoltmeters, potentiometers, thermocouples, radiation pyrometers, resistance thermometers, and pressure-actuated thermometers are described and evaluated. Covered in a similar manner are chapters on humidity and moisture, pressure, flow, liquid level, density, viscosity, speed, and analysis. Chapters ten to fourteen describe various controller mechanisms useful in instrumentation. The final chapter points out the trends in automation and instrumentation.

A glossary of terms is included. The volume is adequately illustrated with drawings and photographs and is well indexed.

This volume should prove useful as a text on instrumentation and control and of interest as a ready reference to engineers in the process industries.

Industrial Detergency. William W. Niven, Jr. New York, Reinhold Publishing Corp., 1955. Price, $8.75.

Reviewed by H. C. Borghetty, Textile Chemicals Department, Rohm & Haas Co., Philadelphia, Pa.

This book meets the demand that has long existed for a concise reference on the application of surface-active agents as cleansing agents for laundry, dry cleaning, textile, food, dairy, and dish washing, metals, and many other uses. It approaches each industry from the practical point of view, thus giving to chemists interested in surfactants the necessary information to follow these products into their various fields of application.

Filling a very important gap between the chemistry of surfactants and their practical applications, *Industrial Detergency* is the work of a group of experts who have abundantly furnished it with engineering data and excellent references concerning all important technical articles in each field.

Up-to-date data on detergents, detergent systems, and building agents is presented, and the correct selection of each type of product is made clear. The many illustrations incorporated are valuable in clarifying the mechanical aspects of the cleansing operations that have been perfected during the last few years.

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